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UNIVERSAL PLATFORM

AND

CARGO RESTRAINT DEVICE

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Aeronautical Systems Division
Wright-Patterson Air Force Base, Ohio
Buyer: T/Sgt L.E. Dean, ASZ.K-1
Initiator: R. Walton, SELM

Prepared By:

Brooks & Perkins, Inc.
Defense Products Division
1950 West Fort Street
Detroit, Michigan
48216

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# FOREWARD

This engineering study report has been prepared to comply with the requirements of contract AF33(657)13582 issued 27 January, 1965 and the contract change notification No. 1 issued 28 May 1965.

Submission of this written report, concurrent with the second oral presentation of ASD on 30 June 1965, completes Items 1 and 2 of the contract.

Leslie Mollon
Leslie Mollon
Program Manager

## ACKNOWLEDGEMENTS

This report is the consolidation at the studies conducted by Brooks & Perkins, Inc. and its subcontractor, Arthur D. Little, Inc. and Eastern Rotorcraft Corporation. Arthur D. Little, Inc. determined the platform requirements and usage and conducted structural materials studies; Eastern Rotorcraft Corporation determined cargo restraint requirements and concepts; Brooks & Perkins, Inc. directed the program and conducted weight and cost studies of alternate universal platform concepts.

Invaluable assistance during the field survey phase of the study was obtained from the officers, enlisted men and civil servants stationed at Scott AFB, Dover AFB, Langley AFB, ASD, WRAMA, Eglin AFB, Fort Belvoir, Army Materiel at Washington, D.C., Fort Lee, Natick Laboratories, A.E. and S.W. Board, XVIII Airborne Corps. and LOGAIR offices at Wright Patterson AFB, and Warner-Robins AFB.

Subcontractor's and contractor's personnel who have made major contributions to the study phase include: Charles Wood, Kenneth Warden, John Watts, and Richard Lindstrom of Arthur D. Little, Inc., Richard Huber of Eastern Rotorcraft Corporation, and Joseph R. Harris, Roy Heady, and Faisel Naffa of Brooks & Perkins, Inc.

# APPENDIX

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FIGURES

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SECTION I

CONCLUSIONS

1. The module which fulfills the size requirements for universality is 44" x 54". However, this module does not meet the design objectives of low cost, low weight, simplicity of design, or ease of field assembly.

2. Future requirements for purchasing 54" x 88" LOGAIR modules are small, in the order of 50 pallets per year.

3. There will be practically no requirement for purchasing 54" x 88" TAC mobility pallets (fork lift table type) for the next ten years.

4. Future requirements for 88" x 108" logistics pallets are estimated to be at least 800 per year.

5. The future requirement for airdrop platform modules is a variable depending on actual use. This requirement easily could be the largest for all module types.

6. The projected requirements for 54" x 88" modules are so small in comparison to the 108" wide modules that they can be neglected from the consideration of a universal module.

7. None of the module sizes, or combinations of modules, offer any advantages over the present module for the Army's airdrop operations.

8. The 108" x 44" module is the best size for meeting requirements of the 108" x 88" logistics pallet and the Army airdrop platform.

9. The 108" x 44" module for Army and Air Force application does not offer any advantages over the two systems in use today.

10. The problems with the proposed universal platform listed above suggest that a cargo and airdrop platform system comprising more than one design and more than one size should be considered.

    Such a system should have the following specific objectives:

    a. Minimum cost per trip for cargo platforms.

    b. Minimum cost per drop for the airdrop platform.

11. The most promising materials for Sandwich Construction for cargo pallets a high-strength phenolic resin-impregnated paper honeycomb faced with high-strength aluminum alloy sheet.

12. Satisfactory performance in puncture and roller-indentation tests indicates adequate compressive strength of the paper honeycomb. Calculations show shear strength may be marginal in specific high-shear areas, but these areas could easily be reinforced by filling the honeycomb with foam.

13. A potential disadvantage of the impregnated paper honeycomb appears to be loss of its compressive strength on water exposure. However, when the panels are properly bonded in manufacture, the honeycomb would be exposed to water only if the panel is structurally damaged in which case the panel strength would be questionable regardless of the condition of the honeycomb.

14. The water resistance and compressive strength of paper honeycomb could be increased markedly by filling the honeycomb with foamed-in-place low density polyurethane foam.

15. The preferred aluminum-facing alloy is 7075-T6 because of its high strength/weight and strength/cost characteristics. Minimum acceptable skin thickness will be governed by maximum loading conditions which are in part dependent on the restraint system.

16. The non-metallic facing materials evaluated in the program will have certain desirable characteristics, but none of the commercially-available materials have strength/weight or strength/cost ratios competitive with 7075-T6 aluminum.

17. The aluminum-faced balsa sandwich construction that is now used has many desirable characteristics, but Arthur D. Little, Inc. limited tests indicate that the sandwich construction itself may be overdesigned thereby increasing cost and weight unnecessarily while some of the attaching parts and methods of attachment are inadequate and cause high-failure rates.

18. The most critical stress condition for the sandwich structure is the 9 G 3-second forward restraint requirement. Since the stresses generated in the panel depend on the interaction of the restraint system, they are difficult to calculate accurately and must be determined in tests.

19. Although the present logistics and air-drop pallets constructed with balsa core and aluminum faces have been in use for some time, little or no detailed analysis or study has been conducted to determine the causes and modes of failure of the present pallets. Information of this sort would be extremely valuable in optimizing design of pallets constructed of new materials and in further defining test conditions for pallets. It was possible to obtain only preliminary information on pallet failures during the field survey regarding module size in the first phase of this program.

20. There will be a continuing need for air-cargo pallets. A changing state of the art in materials and manufacturing processes may provide improved methods for fabricating light weight pallets.

21. The current 463L cargo nets are difficult to apply, inconvenient to store, susceptible to hardware damage, difficult to tension and release, and tangle easily.

22. Two types of cargo restraint are required:

    a. One type to contain bulk cargo loads.

    b. One type capable of single point attachment to bulky equipment on vehicles for air-drop and air support operation.

23. The bulk cargo restraint device described in Section X eliminates the deficiencies listed in Item 21 above.

24. Dacron webbing is the most preferable material for the cargo restraint because of its excellent strength/weight and light resistance characteristics.

25. The selection of webbing size and its orientation within the overall restraint assembly must be coordinated with the platform assembly to avoid imposing excessive loading to the aft edge of the platform.

26. The number of cargo restraint assemblies per loaded platform should be a minimum. Two identical restraints are proposed - one placed longitudinally to the load; the other, laterally.

27. The number of peripherical tie-downs per each side of the platform should be identical. Six are proposed for each edge of the logistics pallets.

28. Considerable restraint device weight savings could be obtained if the device were designed for the probable maximum cargo loads of 5000 pounds.

29. The extration parachute load transfer device presently being developed by the U.S. Army, Natick Laboratories is adequate to meet all load requirements for the forseeable future and may be adapted to the universal air-drop platform.

30. Initial comparison of the relative transportation costs and the production costs of the 463L pallets, assuming an average pallet life and trip distance, indicates that the costs of air transporting the pallets is several times greater than the cost of manufacture.

31. A more easily assembled and disassembled air-drop platform should be developed which will have increased reuseability, especially when used for low level air delivery.

32. The source to user concept of a "building block" type of pallet assembly has been rejected because of the 2 1/4" thickness limitation and the great influence of weight upon transportation costs.

## SECTION II

## RECOMMENDATIONS

1. The study effort should be redirected towards a cost/effectiveness evaluation of the Universal Platform.

2. A "value added" analysis of the detailed requirements of ASNLM Exhibit 63-6 should be conducted to assure that pallets complying with the specification will have minimum cost/maximum performance characteristics.

3. A cost/effectiveness study should be conducted on alternate logistics and air-drop platform (with low level capabilities) systems to achieve:

   a. Minimum cost per trip for the logistics system.

   b. Minimum cost per drop for air-drop operations.

   These cost should include the non-reoccurring development expenses, platform procurement, transportation, servicing and maintenance, inventory charges and replacement costs.

4. Two new design specification should be prepared: one for the logistics pallet, and the other for the air-drop platform with low level capabilities.

5. The catagory II test program should be expanded to evaluate the platforms and restraint devices under actual random use conditions as well as more limited laboratory conditions.

# SECTION III

## BACKGROUND

The objective of this study effort has been to establish the basic design criteria of a low cost Universal Platform and Cargo Restraint device meeting the requirements of ASNLM Exhibit 63-6. In accordance with the contractural requirement, Brooks & Perkins, Inc. accompanied by its subcontractor's Arthur D. Little, Inc. and Eastern Rotorcraft Corporation visited the using commands to review the U.S. Air Force and U.S. Army current and anticipated requirements for platform configurations.

### Description Of The Air Logistics System

While the Air Force has a predominate role in the delivery of military supplies and equipment by air, compatibility with other transportation modes is very important. The general air logistical movement of supplies from a point of origin in the United States to the user in an overseas forward area is illustrated by Figure 1. This flow diagram shows only Air Force and Army supplies. Shipments for other military services and government agencies would follow the same general pattern.

The exact route of an air shipment from CONUS to an overseas destination would depend on many factors. The flow diagram shown contains four segments requiring airlift and two segments requiring surface movement. At the present time the rail or truck transportation segment between the source and the LOGAIR terminal is principally individual piece handling, the LOGAIR movement is on 54" x 88" platforms, the MATS and Air Force Theater Airlift is on 88" x 108" platforms, the Army airlift and surface distribution is again individual piece handling. Even with this distribution system, where cargo unitized at the MATS APOE can move to the Field Army Rear Area without destroying the integrity of the unitization form, there are an estimated 15 different handlings required from the source to the user.

The type of cargo transported and the route structure of the system is influenced considerably by the conditions under which it is required to perform. Operating conditions of the world-wide air logistics system can be classified as "normal" or "emergency", depending on the degree of our military involvement.

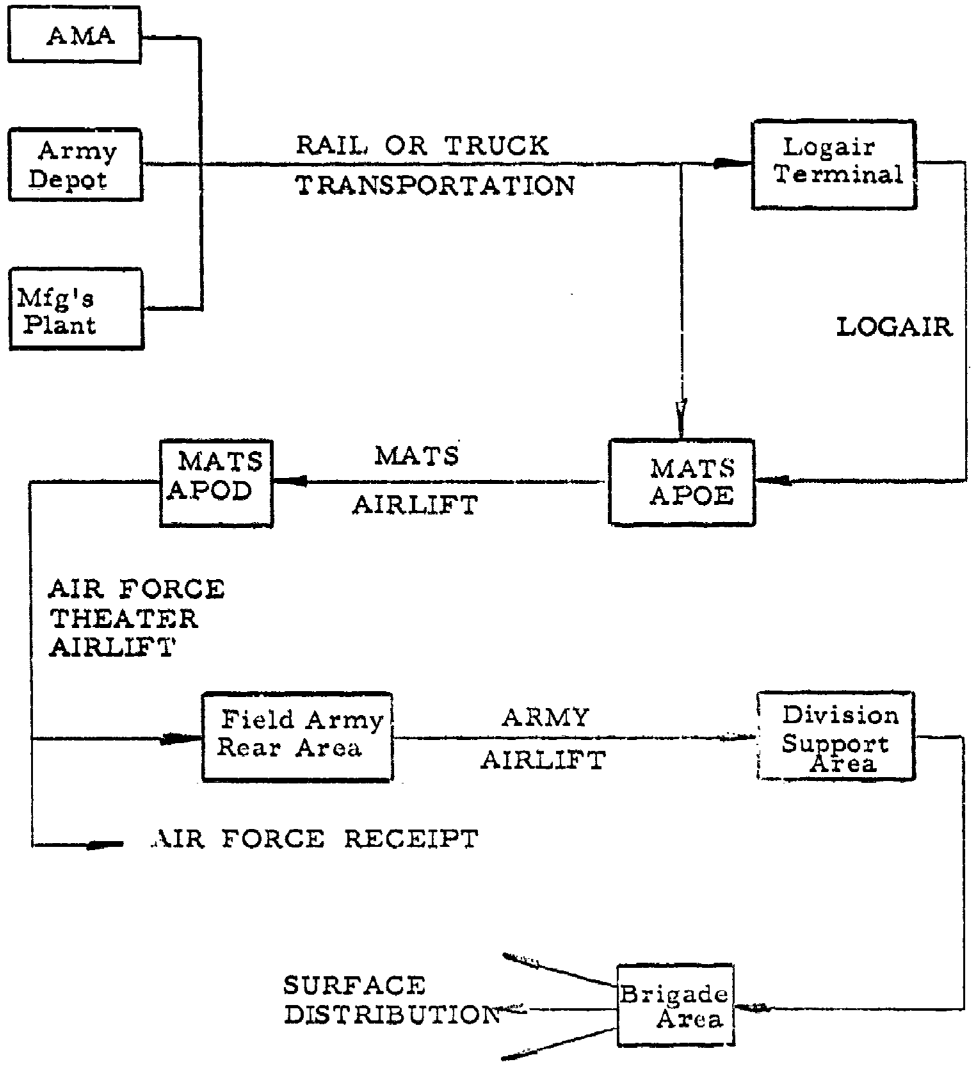


Figure 1. General Logistics Flow Diagram

The "normal" operation of the air logistics system consists of global distribution of military supplies and equipment to United States forces and to allied forces by cargo aircraft operating on a regular schedule. In addition to the regularly scheduled flights, MATS supplies aircraft for special missions where full plane loads of cargo are transported directly from a designated origin (usually in the United States) to an overseas consignee.

An important characteristic of the normal scheduled logistic service is that the Air Force ships the major amount of cargo by this means. Cargo density averages in the 12 to 16 pound per cubic foot range. The flow diagram shown in Figure 1, would describe the usual cargo routing with the exception that the LOGAIR segment would be bypassed by surface transportation for a large amount of the cargo flowing through MATS.

The low average cargo density results in a tendency for MATS aircraft to cube out before grossing out. This situation does not apply to all aircraft, notably the C-124. However, it is a frequent occurrence to cube out aircraft such as the KC-135 even though route segments are 2000 miles or more.

The role of the air logistics system changes considerably during an "emergency" period. The military aircraft normally used for scheduled air cargo operations can be diverted to transporting troops and supporting equipment to the trouble spot. Once delivered, these troops require resupply by air until conventional surface supply lines are established or until the troops are withdrawn. The recent airlift of airborne troops to the Dominican Republic is an example of such emergency action.

Both the basic cargo and route structure changes considerably during an emergency. The average density of Army cargo, exclusive of ammunition, is about 25 lb/ft.$^3$ Ammunition weighs 40 to 50 lbs/ft$^3$ or more. The shift to Army resupply means a much higher probability for grossing out the aircraft.

The route structure of the air logistics system also changes. If daily supplies for troops are shipped from CONUS, the Air Force shortens transit time by loading MATS planes at the most convenient military or commercial air field.

## Description Of Airdrop System

The Air Force supplies the large transport aircraft for airdropping Army supplies and equipment. The rail system designed as a part of the 463L project will accomodate both logistics pallet and airdrop platforms. Hence, any Air Force aircraft having a rail system installed can be used for airdropping Army rigged loads.

During "Normal" times there is practically no requirement to supply troops by airdrop. The Army conducts training for rigging loads and, in cooperation with the Air Force, makes many practice drops. The accepted platforms used for training are modular in construction. They can be combined to make airdrop platforms ranging from 8 feet to 28 feet long in increments of 4 feet. For training, the platforms are recoverable and reuseable to a certain extent.

The chief difference between normal and emergency operation is that there is no assurance of recovering platforms and associated airdrop equipment during an emergency. Various estimates of the percent of items recoverable have been made. However, the Army has very little past experience on which to base these estimates.

The present method of delivering supplies and equipment by parachute is not satisfactory to either the Army or the Air Force. Hence, there is much activity by both services to develop delivery methods that are more accurate, more flexible, less costly, and less vulnerable to ground fire.

Three low level extractions methods are now in development: Ground Proximity Extraction System (GPES), Low altitude parachute extraction system (LAPES), and the parachute low altitude delivery system (PLADS). GPES and LAPES are executed close to the ground thus permitting the platform to free fall. The horizontal velocity or ground impact is far greater than is experienced when the platform is dropped from several hundred feet. LAPES introduces the widest ranges of platform-to-ground altitudes upon impact.

Each of these logistics and airdrop missions have resulted in an individual pallet or platform. A review of the overall usages and requirements is essential prior to establishing the design criteria of the Universal Platform and Cargo Restraint Device.

## SECTION IIIA

## THE RELATIONSHIP OF PALLET SIZE TO AN INTEGRATED AIR MOVEMENT SYSTEM

In addition to their support of the Air Force, three branches of the Air Force can be considered principally as service organizations to DOD because MATS, TAC, and the Theater Airlift organizations supply the airlift capability for most air logistics and airdrop operations. Since it is their cargoes which will be carried, it is desirable that the special problems of the "customers" be considered carefully so that an integrated source-to-user supply system is achieved.

Air Logistical Supply System

There are two possible methods of shipping unitized loads weighing about one ton through the air logistics system. The presently accepted method is to unitize loads on 40" x 48" warehouse pallets and to ship four such loads on the existing unitary 88" x 108" master pallet. The other method would be to design a fork liftable modular pallet that can be joined together in multiples to make a large unit load for air shipment, then disassemble the pallet into the original small components for handling at the output end of the distribution system.

It is widely recognized that the 88" x 108" logistics pallet is too large for unitized handling outside of the Air Force. The Army and Navy have standardized on the 40" x 48" pallet size for unitizing supplies. This unit size is compatible with the MATS master pallet since four of the small pallets can be shipped on a master pallet without undue loss of space. Unit loads of Classes I through IV Army supplies on 40" x 48" pallets stacked 54" high weigh from 1500 lb. to 2000 lb. Class V supplies have much higher density and weigh up to 3500 lb. per pallet load stacked to a height not exceeding 54". Army and Navy supplies shipped via MATS and Theater Airlift on 40" x 48" pallets will nearly always cause the aircraft to gross out. Therefore, with these shipments, the extra cube due to use of the warehouse-type pallets on the large unitary platform is of no consideration. The extra weight of the pallet-on-pallet system (approximately 2% of the cargo weight) is a factor that must be considered. However, any pallet system that might be designed to combine small modules in order to construct an 88" x 108" size would weigh more than the present MATS master pallet.

For light density material, the overall stacking efficiency and the possible stack height would be reduced if loads were built up on pallet modules smaller than the standard 88" x 108" pallet. This would aggravate the existing condition of cubing out most Air Force transport aircraft when the majority of cargo is lower density Air Force Cargo.

The loads of supplies unitized on 40" x 48" pallets offer handling advantages at both ends of the supply system since they can be handled quickly and easily by fork lift trucks. These unitized, fork liftable loads provide the desired feature of intermodal handling and transportation. The pallet is a standard size that will fit commercial and military transport vehicles with a reasonable degree of weight and cube utilization. Such a system would likewise permit acceptance into the airlift system of Army and Navy cargoes in their usual form, thereby providing desirable customer service.

Delivery of Supplies By Airdrop

The present system for delivering supplies by airdrop utilizes a platform having minimum dimensions of 96" x 108". The adoption of this 463L size has created a problem for the Army because the minimum quantity of supplies that can be transported and dropped efficiently is too large for average Army usage. The 463L system has replaced the A-22 container for airdropping supplies. The A-22 is a very simple, lightweight method of rigging and dropping pallet sized loads up to 2200 lb weight and is preferred by the Army for airdropping supplies.

There seems to be no easy solution to this problem since the standard 463L rail width is 108" for airdrop platforms. The Army is presently experimenting with methods of dropping the A-22 containers from aircraft equipped with the 463L roller and rail system. This is an important consideration that should receive further attention by the Air Force and the Army.

## SECTION IV

## PALLETS SYSTEMS - QUANTITY REQUIREMENTS

Four standard pallets are in use today. These are listed in Table I.

TABLE I.

CURRENTLY USED PALLETS AND MODULAR PLATFORMS

| Designation | Size | Forklift Entries |
|---|---|---|
| LOGAIR | 54" x 88" x 2 1/4" | No |
| TAC | 54" x 88" x 4 1/2" | Yes |
| MATS | 88" x 108" x 2 1/4" | No |
| AIRDROP | 48" x 108" x 2 5/8" (Basic Module) | No |

Although the four types of pallets are designed for a specific application, the 463L aircraft rail system with suitable adjustments will accomodate all types. Figure 2 illustrates the chief uses for the various pallets.

### USE OF LOGISTIC PALLETS

Pallet usage for logistic purposes varies from daily use in LOGAIR and MATS to standby duty for TAC. Since acceptance of the 463L concept, the various military services have purchased pallets for their particular application.

#### 54" x 88" Pallets

The two small logistics pallets (54" x 88") are for holding Strike Force supplies in readiness and for use in the LOGAIR SYSTEM. TAC has purchased 4700 pallets for "mobility" loads. It is estimated that this quantity will satisfy the requirement for this application up to ten years in the future.

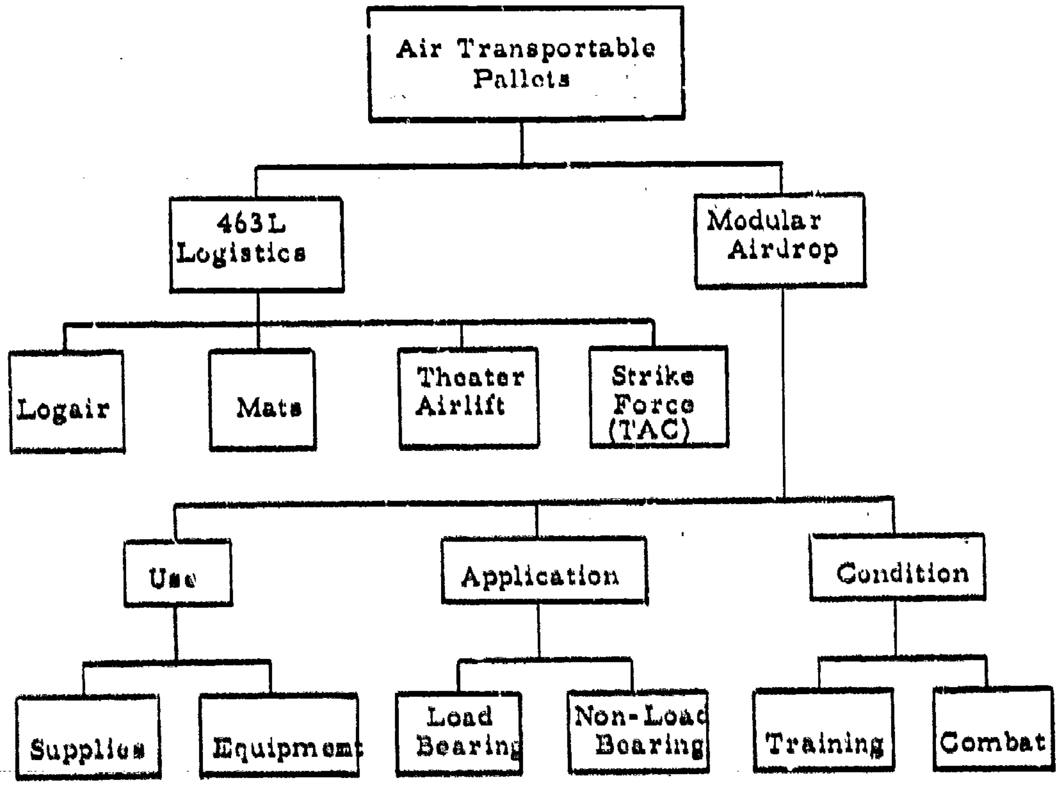


Figure 2. Chief Methods for Using the 463L Pallets

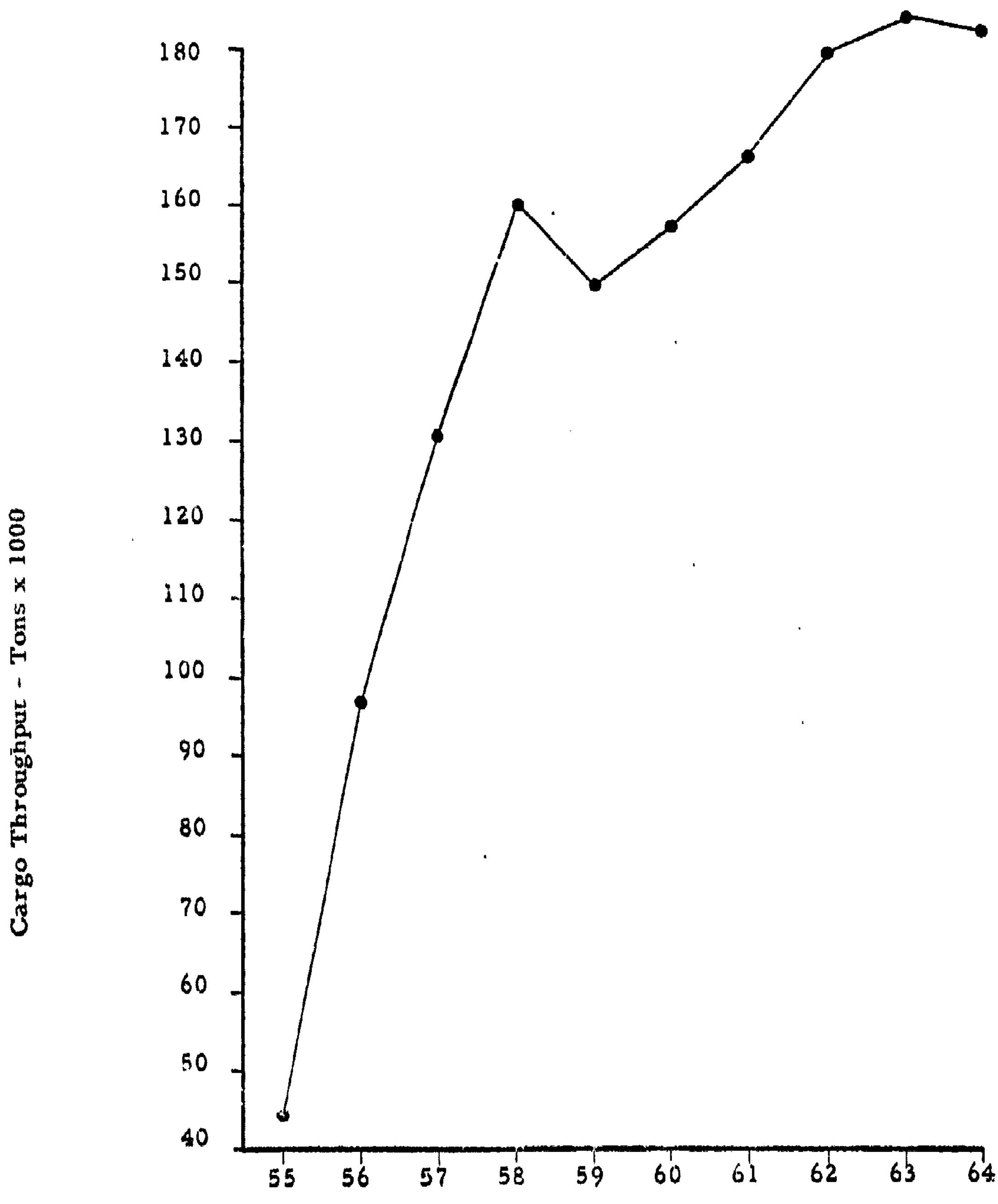


Figure 3. LOGAIR Growth Curve

The LOGAIR System presently handles an annual cargo throughput of approximately 180,000 tons per year. It is expected that LOGAIR will stabilize at about this yearly volume. The growth curve of LOGAIR is shown in Figure 3. The present inventory of useable pallets is approximately 1000. A current purchase of 100 additional pallets plus 50 repairable pallets will bring the total inventory to 1150. Average pallet utilization, based on an estimated 80% of total cargo movement on pallets, is approximately 155 pallet trips per year.

Damage rate for LOGAIR pallets is inherently less than for larger pallets. This is because the construction of both pallets is identical, yet the LOGAIR pallet has to carry only one-half the load. In addition, the small pallet is not normally lifted by the four corners as is required of the large pallet for loading in the C-124 aircraft. Pallet loss or system unbalance are more easily controlled in the LOGAIR system because it operates entirely within CONUS. It is estimated that a replacement rate of 10% per year (100 to 120) will be required.

88" x 108" Pallets

The MATS and Theater Airlift combine to form that segment of the air logistics system moving cargo from an APOE to the designated service. In the European Theater the 322nd Air Division has been combined with MATS. In the Pacific Area, the 315th Air Division operates independently and is not within the framework of industrial funding. Since, the Theater Airlift is an extension of MATS in many instances, and since data is not readily available on this segment of the system, this analysis will deal only with MATS system characteristics. This approach will tend to underestimate the usage of the 88" x 108" pallet since the requirements of a rather important segment of the air logistics system are not included.

Information regarding MATS pertinent to estimating pallet usage and future requirements is shown in Table II.

TABLE II

MATS SYSTEM DATA

| | |
|---|---|
| System Throughput (Average) | 240,000 Tons/Yr. |
| Projected System Growth Rate | 15%/Yr. |
| Percent Palletized Cargo | 50% |
| Average Load/Pallet | 2.1 Tons |
| Projected Avg. Load/Pallet | 2.5 Tons |
| Approximate Number of Pallets at Present | 3,200 |

One of the complicating factors is that there is poor control over pallets because the system extends around the world and pallets are not always returned to the system by the Army and Navy. At the present time an extra pallets are being purchased for the MATS system, to increase the inventory to approximately 10,500 pallets. On the basis of 3,200 useable pallets, the pallet makes one trip every 20 days. With the increased inventory, pallet useage will be about one trip every 2 months.

Using a growth rate of 15% per year in the MATS system, and assuming an attrition rate of 10% per year, the requirement for 88" x 108" logistic platforms is estimated at 800 pallets per year. The 10% attrition is an estimate based on fewer pallet failures in service and better pallet control. Attrition has been as high as 40% per year.

USE OF AIRDROP PLATFORMS

As stated above, the only requirement for airdrop platforms during normal times is for training Army and Air Force personnel in the techniques of rigging and dropping. The recovery rate is 100% and the incidence of damage is rather low. A modular airdrop platform hasan average useful life of four to five drops.

Total purchases of modules since the approval of 463L amounts to approximately 35,000 sections. No estimates are available regarding the present inventory of usable platforms. During an emergency period, the requirements for airdrop platforms would be quite large in comparison to the modular sections purchased to date. For example, if one airborne division were emplaced by airdropping all personnel and equipment, the equipment would require approximately 15,000 4' modules. This assumes no platforms are recoverable.

# SECTION V

## MODULE SIZE DETERMINATION

Choice of a module size for a universal platform is influenced by considerations other than dimensional restrictions. In order to evaluate any proposed module size for universal platform it is necessary to investigate the characteristics of the platform system which is implied by the module size. For example a module size which requires assembly of four modules for a logistic platform may be equally desirable, from the point of view of size alone, as a module size which requires two modules per logistic platform.

The smaller module in this example, however, clearly implies a system different from that of the larger module. Platform strength, cost, weight and ruggedness may be expected to be different. Assembly time in the field would differ, as would the degree of compatibility with airdrop loads.

Consequently, it is necessary to keep in mind the system performance implications of any potential module size. The following discussion identifies possible module size, ranks them in accordance with the general universal platform objectives, and documents selection of the size that is optimal from both the point of view of size objectives and other relevant objectives.

### OBJECTIVES

The objectives to be met by a universal platform include those which specifically relate to module size. In addition, other objectives either influence the module size or are affected by it. Objectives related to size are grouped below in three categories.

#### Stated Size Objectives:

Three objectives specified by the statement of work directly restrict the module size. They are:

- The module shall be of one size.
- The module shall be compatible with 463L equipment and aircraft.
- The module shall be capable of being assembled into a platform of 108" x 88" dimensions.

Stated General Objectives

Several general objectives are also specified by the contract work statement. The first two of these directly influence module size. The others are objectives which either influence or are affected by module size.

- The module shall be of such size that assembled airdrop platforms are compatible with standard airdrop loads.
- Cost of the module should be the minimum possible.
- The module should be readily assembled into platforms under field conditions.
- The module should be capable of withstanding long periods of operational use.
- Platforms assembled from the modules must be capable of being stored outside under worldwide climatic conditions.

Developed Objectives from Field Survey

As a result of communications with a large number of users and managers of military air platform systems, several additional objectives have been established. Objectives resulting from this field survey which relate to size are listed below.

- The module design and operations should be simple.
- The module should withstand several airdrops.
- Platforms constructed of the module should have a high load-bearing strength.
- The module-platform system should provide the greatest possible universality, or applicability to the entire military air logistics cycle.
- The platform assembled from the modules should provide the greatest possible resistance to bowing by the tie-down devices.

- Module that can be assembled into the 54 x 88 inch size currently used by TAC and LOGAIR would be desirable.

- Module size should be such that assembled logistic platforms may be fitted into logistic aircraft with as little space loss as possible.

Module Sizes that Meet Stated Size Objectives

The stated size objectives listed above restrict possible module sizes to a small number of candidates.

In order to establish the minimum feasible module size, consideration was given to the maximum number of modules into which a 108 x 88-inch platform could be divided. Initial engineering analysis of platform cost, weight, and strength clearly showed that the maximum number of divisions of a 108 x 88-inch platform was four modules. In addition, it was determined that dividing either the 108-inch or the 88-inch dimension of the logistic platform into more than two parts would result in excessive platform weight and cost.[1]

Consequently, there are only four module sizes to be considered that meet the stated size objectives. These are designated as:

| Module Designation | Module Dimension |
|---|---|
| A | 44" x 54" |
| B | 88" x 54" |
| C | 44" x 108" |
| D | 88" x 108" |

[1] An exception to this rule was considered. It was suggested that an airdrop module which was significantly "shorter" than the current Army 108 x 48-inch module would provide greater ability to match airdrop platform lengths to airdrop loads. This ability could be provided by a 108 by 29-1/3-inch module -- dividing the 88-inch dimension of the logistic platform into three parts. However, as is shown in the airdrop compatibility sub-section of the discussion of ranking which follows, this smaller module does not provide a significantly better fitting of airdrop load lengths. Consequently, only the four module sizes listed are considered further in this section.

Sizes Meeting Stated Size Objectives Ranked According to Other Objectives

In order to achieve a rational determination of the optimum module size it is necessary to compare the relative performance of each possible module size with respect to the universal platform objectives which are influenced by size. This comparison is made in the form of a ranking table. Discussion of the ranking follows.

A ranking table of the four module sizes designated above as "A", "B", "C" and "D" is presented in Table III according to each of the general and field survey objectives. Ranking is according to preference for any objective.

The module size marked 1 is the least preferred and 4 is best. No weighing of the importance of any objective is included: Table III shows only the order of preference of the four sizes for each objective.

TABLE III

Ranking of Module Sizes Meeting Stated Size Requirements

| Objective | Relative Ranking (1-4, 4 "best") | | | |
|---|---|---|---|---|
| Sizes - | 44"x54" | 88"x54" | 44"x108" | 88"x108" |
| Designation - | A | B | C | D |
| 1. Compatibility with Airdrop Loads | 4 | 1* | 4 | 1* |
| 2. Minimum Weight | 1* | 2 | 3 | 4 |
| 3. Ease of Field Assembly | 1 | 2 | 2 | 4 |
| 4. Minimum Cost | 1 | 2 | 3 | 4 |
| 5. Ruggedness in Logistic Service | 1 | 2 | 2 | 4 |
| 6. Resistance to High-G Impact | 1* | 1* | 2 | 4 |
| 7. Simplicity of Design | - | - | - | - |
| 8. Airdrop Endurance | - | - | - | - |
| 9. Load Bearing Strength | 1* | 2 | 3 | 4 |
| 10. Universality | 4 | 3 | 1 | 1 |
| 11. Resistance to Bowing | 1 | 1 | 4 | 4 |
| 12. LOGAIR, TAC-Size Capability | 4 | 4 | - | - |
| 13. Aircraft Fitting | 4 | 3 | 4 | 3 |
| Average Ranking: | 2.1 | 2.1 | 2.8 | 3.3 |

*Considered to be unacceptable.
-No Significant difference, or no comparison.

It is necesary to establish some ground rules in order to rank module sizes according to the objectives listed above. One problem arises from the fact that module size often does not in itself cause one module to be more desirable than another for any single objective. For instance, if it were possible to design modules, A through D, having the same weight, the cost of each 88" x 108" pallets would be different. In order to rank these four sizes with respect to weight, therefore, it is necessary to consider how the weights of the modules would rank, all else being equal (cost, strength, assembled area, etc.) Each objective, therefore, must be considered with this "all else being equal" approach.

Several of the objectives are closely correlated. For example, modules with high load-bearing strength when assembled into platforms will provide good resistance to bowing. For this reason, it should not be concluded that each objective measure is equally important.

Use of relative ranking may also be misleading, since a ranking of 3 in "cost", for example, may not equivalent to a ranking of 3 in "weight". In Section VIII, discussion of the performance of the Universal Platform Module, reveals the importance of the module weight when used in the logistics pallet. The transportation costs of the pallet become several times greater than the production cost of the pallet. Costs, then should include total costs, i.e. production, transportation, replacement, and maintenance.

Further assumptions made in determining the relative rankings are discussed under each objective heading below.

## 1. Compatibility with Airdrop Loads

Army airdrop platforms are currently constructed from modules assembled to 108 inches width. They are available in 8, 12, 16, 20, 24, and 28 ft. lengths. This assortment of lengths seems to provide an acceptable "match" or fitting of airdrop loads. In some cases, however, platform length is greater than the length of the item placed on the platform, and excessive aircraft cargo space is consumed.

It was felt in the initial phases of this study that an "optimum" module length [1] should be determined, in order to avoid wasting aircraft cargo space with excess platform length. If such an "Optimum" airdrop module length existed, and if it seriously affected the space utilization of the aircraft, this optimum length would become a strong size requirement.

In order to ascertain whether or not airdrop module length imposed a serious size constraint on the Universal Platform module, two studies were made.

The objective of the first study was to discover if airdrop module length seriously affected the capability to match platform length to load length. In this study, rigging of current standard airdrop loads was investigated.[2] No weighing of the importance of any one load was imposed. Current relationships between load lengths and minimum acceptable platform lengths were assumed to be representative of future airdrop loads and thus to provide a basis for a general analysis. Details of this analysis are presented in Appendix 1.

The results of this analysis are shown in Table IVa. Expected aircraft length loss (under stringent assumptions) are shown for five potential module lengths. The 29-1/3-inch, 48-inch and 50-inch lengths, sizes not evaluated here, are included for comparison. Aircraft cargo space loss is in terms of average number of inches of excess platform length divided by average load length.

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1 "length" as used here for airdrop modules, means dimension along the center line of an aircraft with a 108-inch rail system. That is, the "length" of a 108 by 48 inch airdrop module is 48 inches.

2 The U.S. Army TM 10-500 series of airdrop load rigging instructions.

Table IVa indicates that only a 2% improvement in aircraft space utilization is expected by shortening the current 48-inch airdrop module length to 29-1/3 inches. The results suggest, however, that a considerably larger aircraft space loss (8%) is to be expected when aircraft platform length is increased to 88 inches.

TABLE IV

Importance of Module Length on Platform Compatibility With Airdrop Loads

IV(a) Results of General Analysis (See Appendix 1)

| Module Length inches | 29-1/3 | 44 | 48 | 50 | 88 | 88 + 50" |
|---|---|---|---|---|---|---|
| Aircraft Cargo Space Loss, % | 2 | 4 | 4 | 5 | 8 | 5 |

IV(b) Results of Specific Equipment List Analysis (See Appendix 2)

| Module Length inches | 29-1/3 | 44 | 48 | 50 | 88 | 88 + 50" |
|---|---|---|---|---|---|---|
| Aircraft Cargo Space Loss, % | 0 | 0 | 0 | 1 | 9 | 1 |

The stringent assumption in the study should be mentioned. It was assumed that platform extention "out from under" the load was always undesirable. This is not always so in practice for three reasons. First, with many heavy loads, all of the aircraft length cannot be utilized, since the aircraft "grosses out". Second, with combinations of most loads utilization of all of the aircraft length is not possible, since the loads do not match aircraft length exactly.[1] Third, the requirements for spacing between platforms was not included. Different spacings would be required for platforms assembled from the 29-1/3, 44, and 48-inch long modules. Because of these three reasons, the loss of aircraft space is actually overstated. It is believed that only the 8% loss figure associated with the 88-inch long platform is large enough to be significant in actual practice.

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[1] A report by the Airborne Department, Ft. Lee, Va, entitled Airdrop Load Planning Guide for Modular Platforms, for example, indicates that the details of fitting of several combinations of platform lengths produce important fitting problems in the C-130.

A second analysis of airdrop module length was made in order to evaluate the above results for a specific equipment list. A table of airlift equipment for a ROAD Airborne Division was used to represent a typical specific airlift situation. Equipment items carried in numbers of ten or more were studied, and aircraft space loss was calculated, as defined above.

Table IVb summarizes the results of this study.

As the table shows, losses from excess platform length are zero for the 29-1/3, 44 and 48-inch lengths. The 88-inch length, however, would produce an excess of platform length amounting to 9% of the total length of the equipment items considered.

Based on these analyses, the 44-inch length of Module A and C in Table III are considered to have good ability to match load lengths, and are ranked at "4". The 88-inch lengths of modules of B and D are considered to provide poor airdrop load length matching. The 8 or 9 percent loss is considered to be unacceptable, and the ranking is so marked.

2. Minimum Weight

Preliminary design calculations indicate that a common design basis, weights of 108 x 88-inch platform assembled from the four modules under consideration would compare as follows:

| Module (Size) | A 44"x54" | B 88"x54" | C 44"x108" | D 88"x1 |
|---|---|---|---|---|
| Weight of 108" x 88" Platform | 411 lb. | 385 lb. | 385 lb. | 357 ll |

Although the weight figures will undoubtedly change for the final design of any one of the modules, the order of weights should hold for almost any design. A platform built up from module A is heaviest because it requires more total length of strength members along its edges. One made from module D is lightest because it requires the least total length of strength members. Module B should be slightly heavier than module C since the stresses at the module point that must be overcome during impact are considerably higher.

Rankings according to weight, therefore, are in the reverse order of the weights as shown above. The weight associated with module A (i.e. 44" X 54") is considered to be close to an unacceptable level.

### 3. Ease of Field Assembly

With any system of field assembly, the module D is by far superior. Over 30% of the loads listed in the specific equipment list for an airborne division (see appendix 2) could be lifted on an airdrop platform of this size. For airdrop rigging, therefore, the larger module could be expected to require much less field assembly. In addition, almost all logistic loads could be carried directly on Module D.

Module A will require the most effort for field assembly Approximately 50% more labor is required to assemble a full size logistics pallet from module A than is required to make the pallet from B or C modules.

Module B and C may be considered essentially equal in ease of assembly, though considerably inferior to D. They are, consequently, assigned to a ranking of 2.

### 4. Minimum Cost

Preliminary design and cost calculations indicate that a 108" by 88" platform made up from the four module sizes may be expected to cost as follows, in lots of 500 - 1000 or more:

| Module (Size) | A 44"x54" | B 88"x54" | C 44"x108" | D 88"x108" |
|---|---|---|---|---|
| Cost of 108" x 88" platform | $316 | $307 | $307 | $281 |

Cost ranking derives from the same factors as does weight ranking; for equal area, module A requires the greatest amount of high-cost rigid edge members, Module D the least. In addition, more fastening devices are required in any useful arrangement of module A, less in modules B and C, and least for module D.

Modules are ranked with respect to cost, therefore, in the inverse order of their costs as shown above.

5. Ruggedness in Logistic Service

The relative ruggedness of platforms made up of the four modules will be affected by several factors. In general, module D will be more rugged, more rigid, and inherently stronger than the others. This superiority results from the fact that a platform consisting of module D relies upon the very efficient structural continuity from edge to edge.

One of the most frequent sources of service damage to current logistic platforms is impact damage to the edges. If the smaller modules are assembled into logistic platforms using separate side-rails and seldom disassembled, they may resist this type of service damage as well as the larger platform. However, to the extent that they are disassembled, handled, or reassembled in a different configuration, (e.g., airdrop) they may be expected to receive more damge to their mating edges. Consequently, module A, having two edges which must remain within close tolerances, for any mating, can be expected to fail more frequently than the others.

Modules B and C would be essentially equal in this respect, but neither are as invulnerable to damage as module D (i.e. 88" x 108").

6. Resistance to High-G Impact

Study of the stresses that may be expected in the aircraft platform during specified loadings indicates that the most critical platform member is the rear edge of the platform during the 9G forward test condition. This member is loaded vertically by the cargo net and acts like a pin-ended beam. The highest stresses will occur at the center of this edge member. Bending to failure is to be avoided. Stiffness sufficient to resist excess bending is also crucial, since if the platform bends too much, the load will come out of the rails and become a missile during impact.

The analysis showed that, all else being equal, the continuous sandwich construction and single extrusion edge member of module D will provide superior strenght and stiffness.

Models A and B are inferior as impact-resistant elements, since a logistic or airdrop platform assembled from these modules will have a longitudinal joint in the middle of the width dimension for 108-inch rail systems. The cost and weight necessary to provide sufficient strength and stiffness would be prohibitive.

Module A and C platforms would also have a cross-width joint when used in aircraft with 88-inch rail systems. In the 88-inch LOGAIR Rail system, however, the load on the platform would be less. The stresses in the rear edge member also would be less for an 88-inch rail system than for a 108-inch rail width since the rear edge member is shorter.

Consequently, module D is preferred; A and B are considered to be unsatisfactory and C is marginal.

## 7. Simplicity of Design

All four module-platform systems under consideration would be of similar design. Whether with detachable or integral side-members, each module would require some joining to make longer airdrop loads. Module D would require considerably less joining, as discussed above, but the design and operating principles are assumed to be of equal simplicity.

## 8. Airdrop Endurance

It is not evident that any of the four sizes would be superior in this category. Platform D, with greater integral strength, would better withstand the shock of edge-landing, and load "rebound". Partially offsetting this is the possible ability of replacing locally damaged panels with modules A, B and C.

No relative ranking is assigned for this category.

9. Load-Bearing Strength

Module D should be superior in this regard. The continuous-skin sandwich construction logistic platform, only possible with Module D, is the most efficient section for strength and stiffness. Logistic platforms assembled from Module A are counted as inferior, since joints would divide their surface in two directions.

10. Universality

Figure 1 in Section III describes the overall flow of air cargo for combat and peacetime logistic cycles.

It is possible that the 44" x 54" size could move from "source" to "user" in both cycles. This size is close to the standard 40" x 48" warehouse pallet used in commercial, Army, and Navy warehousing and shipping. In theory, cargo could be palletized at a manufacturer's warehouse, shipped to Army or Navy depot, joined together in blocks of four to move through the MATS system, and if necessary, broken down into blocks of two to be loaded into army aircraft. In addition, sufficiently varying lengths of airdrop platforms could be constructed with the modules for either 88" or 108" rails. (Module A is therefore compatible in assembled sizes with the MATS 108" rail system; and with the TAC, LOGAIR, and experimental Army CV-7- 88-inch rail system.) If desired, the single loaded modules could be carried in the Army 3/4-ton and 2 1/2-ton trucks, the 3/4, 1.5, and 2.5 ton trailers, or M274 carrier (mule); six of the eight most numerous cargo-carrying devices that may be expected to be available in combat zones.

Several disadvantages are attached to this source-to-user concept, however. The most serious are high weight, cost, and complexity of larger pallets made up of A sized modules. These disadvantages arise from the need to fasten the modules together so that they are strong enough to meet operational stresses. Another disadvantage is that increased labor, material, and weight would be required per platform for netting the four smaller A modules. Poorer cube utilization in aircraft may be expected with platforms assembled from small modules individually loaded than with larger modules.

These disadvantages, however, are considered above under the other performance measures. From the point of view of universality alone, System A must be considered best.

The major difference between the universality of module B and modules C and D is that the 54" x 88" size currently used by TAC and LOGAIR is not achievable by the latter two modules.

11. Resistance to Bowing

A serious difficulty with present platforms is that tie-down hardware is capable of exerting sufficient vertical force on the platform edges to bow the platform. This bowing often prevents entry into the aircraft rail systems.

Modules D and C, with continuous skins across the 108" width, will be superior in resistance to this bowing tendency, since greater stiffness is possible with these modules, as discussed above.

12. LOGAIR, TAC-Size (88 x 54-inch) Capability

Modules A and B may be used to replace the 88 x 54-inch platforms currently used by LOGAIR and TAC, and the few platforms of that size used in the MATS system.

As discussed above under platform usage, however, the replacement needs of the LOGAIR and TAC systems for modules of this size are small relative to those of the MATS and Airdrop pallet systems. Consequently, this criteria is not considered a critical one.

13. Platform Fit in Aircraft

Current logistic platforms do not provide exact fitting of cargo aircraft. The table which follows shows possible utilization of cargo compartment space with the 88 x 108-inch platform, which corresponds to module D.

TABLE V

Platform Fit in Military Aircraft

| Aircraft | Cargo Compartment Length | | Number of 108" by 88" platforms Possible [1] | Approximate Compartment Loss, Inches | Loss in Length, Percent |
|---|---|---|---|---|---|
| C-124 | 924" | (77') | 10 | 26 | 3 |
| C-133 | 1168" | (97' 4") | 13 | 0 | 0 |
| CV-7 | 377" | (31' 5") | 3 | 49 | 13 |
| C-141 | 840" | (70') | 9 | 32 | 4 |
| C-141, Inc. Ramp | 972" | (81') | 10 | 74[2] | 8 |
| C-130 | 497" | (41.4') | 5 | 49 | 10 |
| C-135 | 1223" | (101' 11") | 13 | 55 | 4 |

[1] Assuming a 2" spacing between platforms.

[2] Not directly comparable.

It is apparent that the 88-inch length is a poor fit for the C-130 and CV-7. The C-130 and C-135 problem would be relieved if module A or C were adopted, since a "half-platform" might be loaded into the 49-inch space. The CV-7 misfit could not be improved by using A or C, since insufficient space remains to load a half-platform.

Consequently, modules A or C are to be slightly preferred over modules B and D for logistic platform fit.

## Optimum Module Size Meeting Objectives

From the ranking table and discussion above, it is apparent that module D, the 108 by 88-inch module is more consistently preferable than the other three. Module size D, however, suffers from the serious inability to provide efficient airdrop load length matching. Using module D as an airdrop module, roughly one foot in each ten feet of aircraft length would be occupied by superfluous platform.

Module C, the next most consistently desirable platform, is to be preferred over A or B both by virtue of its higher ranking, and since it does not, as do A and B, have marginal performance in any of the ranking categories. Module C, therefore, is selected a s the optimum size that meets the stated size requirements.

Module C may be viewed as the best compromise between module D's inherent strength superiority and the greater size flexibility of module A. Two modules of C would be required for a 108-inch wide logistic platform. This platform, however, could be adjusted to accommodate longer logistic loads than the MATS pallet can carry now. When used as an airdrop platform, C would be joined by a system of separate side-rails. Field assembly with hand tools should be rapid. An inventory would be required at assembly areas of side-rails of the various lengths required.

It is interesting to note, from the above analysis which results in Table III, that only one serious drawback keeps module D from being clearly superior. This drawback is the inability of the 88-inch length of module D to match airdrop loads with sufficient efficiency.

Module Thickness

As specified in the work statement, the module thickness should be 2 1/4". However, a full systems study of all factors affecting module thickness (such as cost, strength, stiffness, weight, and cube loss) would result in an optimum module of different thickness.

Extension Of Platform Width To 120-Inches

An objective of the universal platform system specified in the work statement is the capability to be assembled into platforms 120" wide. This width increase would be accomplished by adaptors added on the 108-inch width of a logistic system. The 108-inch rail system would continue to be employed.

Meeting this objective is a problem in the design of adaptive side-rails. The effectiveness of any module size, and hence the optimum module size, is not affected by this objective. Consequently, this objective was not included on the above determination of the best module size within the constraints imposed by the work statement.

System Performance of Optimum Module Size

The 108" by 44" module size is the best choice for a single-sized universal module for logistic and airdrop use. As a platform system, however, it shows no clear advantages over the system and sizes currently in use. Section VIII expands on the capabilities and limitations of the universal platform concept when limited to the use of only one module size.

# SECTION VI

## MODULE MATERIAL SELECTION

The current 463L pallets and modular type airdrop platforms are fabricated from -

a. 6061-T6 aluminum alloy extruded edge members.

b. 6061-T6 and 7075-T6 aluminum alloy sheets for the upper and lower surfaces.

c. Edge-grained balsa wood core.

d. Urea and epoxy adhesives.

e. Alloy steel tie-down rings.

These materials have proven to be satisfactory from the standpoint of structural performance and environmental resistance to climatic conditions. During this study, and objective review of design requirements and material properties was conducted to determine the minimum material and production cost of the universal module.

Operational usage of the logistics pallets (i.e. corner suspension and the alternate longitudinal orientation of the pallet) dictates that the pallet have bi-directional structural characteristics. A sandwich type construction is recognized as the lightest and most economical structure for this type of loading. A low density core resists local impact loadings and distributed shear forces; a high density material resists the bending forces. Selection of the optimum core and skin materials requires a cost/performance evaluation of potential materials and the determination of the minimum performance requirements of the structural element.

The physical properties of broad range of metallic and non-metallic materials were reviewed to determine the most promising skin and core materials. Several variations of alternate materials were combined into a series of sandwich panels subjected to puncture and roller indentation resistance tests.

SELECTION OF CORE MATERIAL

A comparison of the cost and physical properties of various core materials is shown in Table VI. Table VIA shows bar graphs of the various properties for each core material so that the relative values can be more easily visualized. Table VIB shows relative values of strength/weight, strength/cost, and strength/weight x cost for various core materials. Although great care must be used in interpreting such a table because there is no weighing of importance of the different factors, this type of comparison can be useful. For instance, this table clearly shows that on the basis of strength/weight and strength/cost ratios individually, balsa is equal to or better than all other cores. However, when both weight and cost are considered along with compressive strength, the paper honeycombs show up to good advantage. Although the strength/weight x cost ratio is very high for some of the low-density honeycombs, they cannot be used because they have inadequate compressive strength.

Balsa Wood

Balsa wood has been extensively used as the core material in the 463L platforms and Army modular platforms for airdrop. Balsa is desirable as a core material because of its relatively high compressive strength, 800 to 1000 psi, and its good shear strength, which is 200 to 300 psi, depending upon moisture content and density. If the balsa wood remains wet for an extended period of time, it may be subject to fungus attach which would seriously deteriorate its strength. The primary disadvantages of balsa are the lack of domestic supply, relatively high density, high cost, and lack of uniformity. The density varies from a 4 pcf to 16 pcf within a single tree. The segmenting of the tree, grading, sorting and mixing the various densities into the proper average density consumes many man hours of labor.

TABLE VI

CORE MATERIAL CHART

| Material | Density lbs/cu ft | Cost/sq ft 2-inch thick | Compressive Strength (psi) | Shear Strength (psi) |
|---|---|---|---|---|
| Balsa | 7.5-9 | $ .90 | 800-1000 | 200-300 |
| Paper honeycomb Douglas Aircomb Style 125-35 Type 20 | 3.4-4.0 | .54 | 450 | 110 |
| Paper honeycomb Hexcel 99/5/16/25 | 4.0 | .50 | 395 | 72-140 |
| Paper honeycomb Hexcel 99/3/8/25 | 3.9 | .46 | 275 | 75-175 |
| Paper honeycomb Union-Camp 50/1/4/18 | 3.3 | .50 | 270 | 80-115 |
| Paper honeycomb Hexcel 60/1/2/25 | 2.4 | .26 | 170 | 32-65 |
| Paper honeycomb Hexcel 80/3/8/18 | 2.7 | .28 | 165 | 65-95 |
| Paper honeycomb Union-Camp 80/1/2/18 | 2.25 | .20 | 170 | 40-59 |
| Foam-filled paper honeycomb Union-camp 80/1/2/18 1.5 lb/ft$^3$ urethane foam | 5-6 | .70-.80 | 400 | - |
| Urethane foam slab U.S. Gypsum Zer-O-Cell | 4.5 | 1.40 | 75 | 70 |

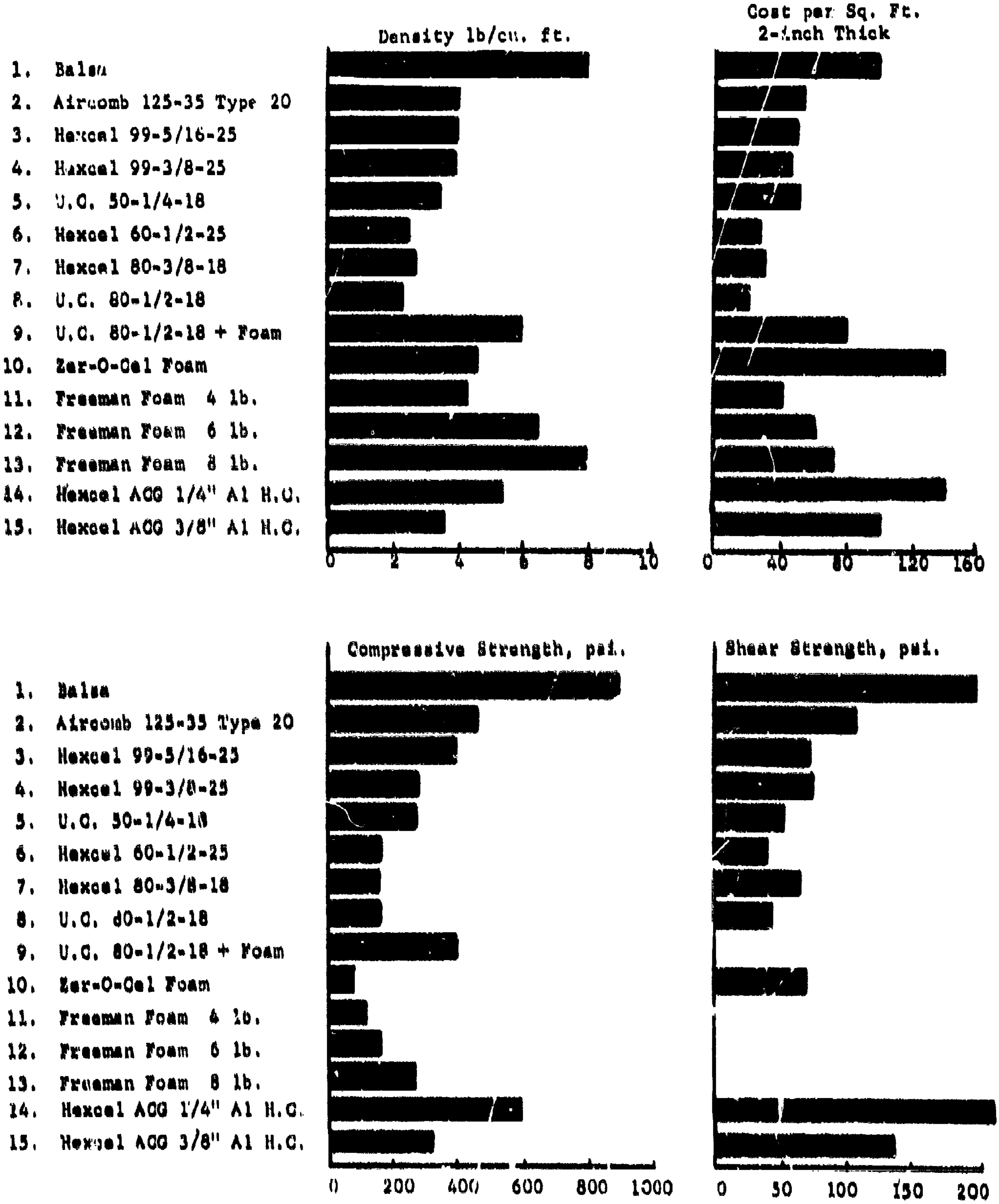
## BROOKS & PERKINS

| | Material | Density lbs/cu ft. | Cost/sq. ft 2-inch thick | Compressive Strength (psi) | Shear Stre (psi) |
|---|---|---|---|---|---|
| 11. | Urethane foam Freeman 1428/1325 | 4.3 | .40* | 113 | -- |
| 12. | Urethane foam Freeman 1428/1325 | 6.5 | .60* | 175 | -- |
| 13. | Urethane foam Freeman 1428/1325 | 8.0 | .73* | 270 | -- |
| 14. | Aluminum Honey-comb 1/4 -.003 ACG | 5.2 | 1.40 | 595 | 213 - [illegible] |
| 15. | Aluminum Honey-comb 3/8-ACG-.003 | 3.6 | .98 | 323 | 130 - [illegible] |

*Raw Materials cost only.

TABLE VI A

BAR GRAPHS - PROPERTIES OF CORE MATERIALS



## TABLE VIB

### STRENGTH-COST-DENSITY RELATIONSHIPS

| | Compression Strength / Density x cost | Shear Strength / Density x cost | Compression Strength / Density | Shear Strength / Density | Compression Strength / Cost | Shear Strength / Cost |
|---|---|---|---|---|---|---|
| Balsa | 124 | 37 | 110 | 33 | 1100 | 33 |
| Aircomb | 210 | 51 | 110 | 27 | 830 | 2[illegible] |
| Hexcel 99/ 5/16 /25 | 198 | 70 | 99 | 35 | 790 | 28 |
| Hexcel 99/ 3/8 /25 | 160 | 97 | 70 | 45 | 600 | 38 |
| UC 50/1/4/18 | 164 | 70 | 82 | 35 | 540 | 23 |
| Hexcel 60/1/2/25 | 270 | 103 | 70 | 27 | 650 | 25 |
| Hexcel 80 / 3/8 /18 | 220 | 125 | 61 | 35 | 590 | 34 |
| UC 80/1/2/18 | 390 | 131 | 75 | 26 | 850 | 29 |
| Form-Filled Honeycomb | 90 | -- | 67 | -- | 530 | -- |
| 8-lb. Foam | 47 | -- | 34 | -- | 380 | -- |
| Aluminum honey-comb 5.2 pcf | 82 | 48 | 114 | 67 | 426 | 24 |
| Aluminum honey-comb 6.9 pcf | 53 | 31 | 114 | 67 | 368 | 21 |

The lack of domestic supply is a primary deterrent to the use of balsa wood as a core material. It is not grown domestically and must be imported from South America. Therefore, it is possible that the supply could be cut off during an international crisis or other shipping interruptions. Although the supply has been adequate to date, future requirements, especially for airdrop platform may exceed the supply.

The density of the balsa cores now used averages close to 9 pounds per cubic foot. Although this density is not high in proportion to the compressive strength and shear strength, laboratory tests indicate that the core of the present 463L and modular pallets may be overdesigned. Since the weight of the platforms and associated transportation costs are important, consideration should be given to reduction in core weight if this can be done without adversely affecting the over-all performance of the pallet. The limited tests that we have run in this program indicate that certain paper honeycombs, which have a density of approximately 4 lbs. per cubic foot, show promise of performing adequately under defined test conditions. Since there are approximately 11 cubic feet of core material in an 88" x 108" pallet and the paper honeycomb weighs 4 lbs. per cubic foot as opposed to 9 lbs. per cubic foot for the balsa wood, there is a possibility of a weight reduction of 55 lbs.

The cost of the balsa wood core is approximately $.90 per square foot for a 2-inch thick core, or nearly $60.00 for an 88 x 108-inch platform. This cost is not high in comparison with the physical properties of the balsa, but if cost reduction can be achieved without decreasing the serviceability of the platform, it would be desirable. The cost of paper honeycombs that appear to perform satisfactorily are in the range of $.50 per square foot, 2 inches thick. The use of these honeycombs could result in a cost reduction for the core material of approximately $26.00.

Resin-Impregnated Paper Honeycomb

Paper honeycomb is available from several suppliers, including Hexcel Products, Inc.; Union Bag-Camp Paper Corporation; and Douglas Aircraft Company, Aircomb Division. Paper honeycomb is made with paper of basis weight of 50 lbs. to 125 lbs. per ream in cell sizes from 1/4 inch to 1 inch or more.

There are two processes for making impregnated honeycomb. One method is called the pre-impregnation process.

The second process is called post-impregnation. The post-impregnated honeycomb generally has slightly better physical properties than the pre-impregnated type, but is available in a more limited selection of panel widths and sizes and is more expensive than the pre-impregnated type. Douglas is the prime user of post-impregnation among the commercial suppliers.

It is possible, at some increase in cost, to use a combination of the pre-impregnation and post-impregnation processes. From our work it appears that such a combination might be desirable in order to improve the water resistance of the impregnated honeycomb. In a combination process, sheets of the desired size of pre-impregnated expanded honeycomb would be dipped in a phenolic resin bath, dried, and cured. This combination product should also have improved physical properties.

The impregnated paper honeycombs are made by Hexcel and Union Camp generally described by three numbers which indicate paper basis weight, cell size, and percent resin in the paper.

The basic advantages of impregnated honeycomb are high strength-to-weight ratio, low density, low cost, good dimensional stability and good resistance to fungus. Furthermore it is domestically produced from readily available materials, and substantial production capacity exists in the country. Additional production facilities may readily be put into operation in case of a national crisis.

The disadvantages of paper honeycomb are its lower compressive and shear strengths than balsa and lower resistance than balsa to loss of strength when wet. However, with some minor design changes it should be possible to completely seal the panel so that water would have access to the panel interior only if the panel is damaged in which case its strength would be questionable even without core damage.

Arthur D. Little, Inc. tests with paper honeycomb indicate that in order to obtain the necessary puncture and roller indentation resistance, compressive strengths of more than 200 psi in the unfaced core are necessary. Paper honeycombs in this range that Arthur D. Little, Inc. has tested include Hexcel 99/ 3/8 /25 (99 lbs. paper, 3/8" cells, 25% impregnation) (275 psi); Hexcel 99 5/16 /25 (395 psi); Union-Camp 50/ 1/4 /18 (270 psi); and Douglas Aircomb Style 125-35 Type 20 which is made with 125 lbs. paper, 35% impregnation and 7/16" cell size (500 psi). Although some honeycombs with lower compressive strength can satisfactorily pass the puncture and roller indentation tests if sufficiently stiff skins are used, Arthur D. Little, Inc. does not recommend their use unless future testing proves them satisfactory.

Calculations indicate that the shear strength of the paper honeycombs may be marginal in certain parts of the pallet under specific loading conditions. The shear strength in these areas could be improved by filling the honeycomb with a high-density polyurethane foam in those specific areas.

Overall Arthur D. Little, Inc. believes that the impregnated paper honeycombs represent the most promising core material in terms of adequate physical properties combined with reduced cost and weight in comparison with the present balsa wood core. Their applicability will depend in part on whether the rest of the panel is so constructed as to eliminate the entry of liquid water into the panel.

Resin- Impregnated Cloth Honeycomb

Excellent compressive and shear strength can be achieved with the phenolic resin impregnated cloth honeycombs, however, they are very expensive ($4-8 per square foot, 2-inches thick) and are made only in relatively small volume for specialized uses. It appears that if a more expensive core is to be used, aluminum honeycomb would have a weight and cost advantage over the impregnated cloth types.

Polyurethane Foam

Rigid polyurethane foams have been evaluated as core materials. These foams can be made with a wide range of physical properties and densities. They are resistant to water, moisture, and fungus attack under normal conditions.

The urethane foams can be incorporated into sandwich structures in either of two ways. They can be foamed in place between skin materials, and they can be cast as slabs in which skin materials are later bonded. Better control of density and physical properties can be obtained in the pre-foamed slabs, but the foam-in-place process is more economical both in terms of process costs and elimination of the adhesive that must otherwise be used to bond the facing material to the pre-foamed slab. In the foam-in-place technique, no additional adhesive is necessary because the urethane resin forms a bond to the skins as it foams.

Arthur D. Little, Inc. tests indicate that polyurethane foam must be in the range of 8 lbs. per cubic foot or higher in order to provide adequate compressive and shear strength as a core material. At these densities urethane foams are less desirable than impregnated paper honeycombs in strength per unit weight and per unit cost. Their only specific advantage over paper honeycombs is better water resistance.

Foam-Filled Honeycomb

The theory of foam-filled honeycomb is that even a very low-density foam will have sufficient strength to prevent buckling of the honeycomb walls and thereby substantially increase the compressive strength of the honeycomb. The use of a urethane foam in the honeycomb cells also substantially reduces water penetration of the impregnated paper honeycomb if it is exposed to liquid water.

In order to evaluate improvements in strength properties and water resistance that might be achieved in a urethane foam-filled honeycomb, several specimens were prepared. To demonstrate improvements in strength properties, honeycombs that were marginal when used unfilled were utilized in these tests. These honeycombs were Union Bag-Camp Paper 80/ 1/2 / 18, and Hexcel 80/ 3/8 /18.

At Arthur D. Little, Inc. the two honeycombs were filled with a nominal 1.5 lb. per cubic foot urethane foam. It should be noted that although the foam is a 1.5 lb. formulation, higher density regions occur adjacent to the cell walls having the during the foaming process so that the over-all increase in core density due to foaming is 3 to 4 lbs. per cubic foot. Strength tests showed that the foam increased the compressive strength of the 80/ 1/2 /18 honeycomb by more than 100% to approximately 400 psi, and reduced the strength loss due to water exposure to less than 25% as compared with a 50 -75% loss for the unfilled honeycomb.

We have not been able within the scope of this program to accurately determine production costs for this type of honeycomb since it is not now commercially available. However, we estimate an add-on to the base cost of the honeycomb of approximately \$.40 - \$.50 per square foot of core 2-inches thick for materials and processing to foam a 1.5 lb. foam in place in the honeycomb. On this basis we might expect a density of 5-6 lb/cu. ft. and an over-all core cost in the range of \$.60 - \$.80 per square foot for a foam-filled 80/ 1/2 /18 honeycomb. If the higher-strength honeycombs are filled with foam, they might show a comparable increase in properties and even approach the strength of balsa at a cost equivalent to balsa and an equal or slightly lower density.

Although foam-in-place foam-filled honeycomb of the type that would be useful for pallets is not now commercially available, at least two of the honeycomb manufacturers have an interest in this field. They are now producing some similar products or have produced such products in the past and we understand they would be able to do so again.

Aluminum Honeycomb

Table VI, VIA, and VIB present cost, weight and strength data on two of the many cell sizes and densities of aluminum honeycomb which are commercially available. It is readily apparent that the cost of the material places it at a disadvantage when compared to balsa wood or resin-impregnated paper honeycomb.

Steel Honeycomb

U.S. Steel Company is currently developing a steel honeycomb material made from .005 cor-ten steel formed and bonded into a 3/8" cell configuration. (See Appendix 3 for a detailed description of the honeycomb.) Production quantities of the material are not yet available. The weight of this material, approximately 12 pounds per cubic foot eliminates it from serious consideration.

U.S. Steel had also proposed a modification of their Air-Dek material for the Universal Platform. It would be 1 5/8" thick rather than the 2 1/4" specified in the Statement of Work. It would be a bonded assembly of an "egg-crate" core and thin gage steel sheets. Although the low raw material costs at first evaluation seem to be attractive, the large amount of manufacturing operations and lack of production facilities make this pallet more expensive than the currently used pallets and platforms. Furthermore, the weight of steel platform is much higher than the conventional light-weight pallets. It may have limited application as a reuseable training airdrop platform providing appropriate repair procedures were available.

Recommended Core Material

The studies and test data (Table VIIC, page 58) indicate that the resin-impregnated paper honeycomb should be used as the core for the Universal Platform Module.

## SELECTION OF FACING MATERIAL

Data regarding the facing materials is first summarized and then each material is discussed in detail. A comparison of strength, cost and weight of various facing materials is shown in Table VII. Several examples of aluminum alloy and steel are included for purposes of comparison. The relative strength figures indicate that the polyester and epoxy fiber glass laminates and one-half inch fir plywood are competitive with aluminum, but other factors such as cost, weight, and quality control make these materials less desirable. Table VIIA shows in bar graph from the weight per square foot, cost per square foot, and relative tensile strength of the materials in order to aid visualization of the differences.

Table VIIB gives relative figures for strength/weight, strength/cost, and weight/strength x cost for the various materials. In interpretation of this type of data, care must be used as explained in connection with similar figures for core materials. In strength/weight ratio, the only materials that are competitive with the aluminum are the filament-wound polyester and the epoxy-glass cloth laminate. The former is not commercially available and would present edge attachment problems while the latter is extremely costly.

## TABLE VII

## FACE MATERIALS CHART

| | Material | Thickness | Density pcf | Wt/Sq ft | Cost/lb | Cost/ Sq ft | Tensile Strength psi | Relative[1] Tensile Strength |
|---|---|---|---|---|---|---|---|---|
| 1. | Polyester/fiber glass 4-oz mat 1 layer 181 cloth | .125 | 96 | 1.00 | .35 | .35* | 25,000 | 3100 |
| 2. | Polyester/fiber glass Woven roving | .125 | 106 | 1.10 | .50 | .55* | 32,000 | 4000 |
| 3. | Polyester/fiber glass 8-ply 181 cloth | .125 | 110 | 1.15 | 1.15 | 1.32* | 36,000 | 4500 |
| 4. | Polyester/fiber glass Filament wound | .125 | 144 | 1.50 | .50 | .75* | 100,000 | 12,500 |
| 5. | Epoxy/fiber glass FR-45 | .093 | 112 | .87 | 3.00 | 2.60 | 50,000 | 4600 |
| 6. | Paper/phenolic Formica S-52 | .060 | 88 | .44 | .54 | .24 | 20,000 | 1200 |
| 7. | Paper/phenolic Formica S-52 | .093 | 88 | .675 | .54 | .36 | 20,000 | 1850 |
| 8. | Paper/phenolic Micarta | .125 | 88 | .90 | .58 | .52 | 18,000 | 2250 |
| 9. | Cotton/phenolic Formica CN | .060 | 88 | .44 | 1.06 | .47 | 11,000 | 660 |
| 10. | Cotton/phenolic Formica CN | .093 | 88 | .675 | 1.06 | .72 | 11,000 | 1050 |
| 11. | Melamine/fabric Formica Q236 | .060 | 98 | .49 | 1.22 | .60 | 13,000 | 780 |

*Materials cost only
1 Relative tensile strength = tensile strength in psi x thickness in inches
2 Not commercially available.

TABLE VI(CONTINUATION)

| | Material | Thickness | Density pcf | Wt/sq ft | Cost/lb | Cost/ Sq. ft | Tensile Strength psi | Relative[1] Tensile Strength |
|---|---|---|---|---|---|---|---|---|
| 12. | Melamine/fabric Formica Q236 | .093 | 98 | .74 | 1.22 | .90 | 13,000 | 1200 |
| 13. | Tempered hardboard Abitibi S2S | .157 | 59 | .77 | -- | .09 | 3,500 | 610 |
| 14. | Tempered hardboard Masonite | .250 | 72 | 1.50 | -- | .20 | 4,000 | 1000 |
| 15. | Fir Plywood | .250 | 36 | .75 | -- | .13 | 5,450 | 1350 |
| 16. | Fir Plywood | .500 | 36 | 1.50 | -- | .20 | 4,670 | 3100 |
| 17. | Birch Plywood | .125 | 43 | .60 | -- | .14 | 7,500 | 940 |
| 18. | Birch Plywood | .250 | 43 | .90 | -- | .14 | 7,100 | 1800 |
| 19. | Aluminum 6061-T6 | .060 | 178 | .889 | -- | .40 | 38,000(u) | 2300 |
| 20. | Aluminum 7075-T6 | .080 | 174 | 1.13 | -- | .57 | 72,000(u) | 5800 |
| 21. | Aluminum 7075-T6 | .050 | 174 | .725 | -- | .45 | 72,000(u) | 3600 |
| 22. | Aluminum 7075-T6 | .063 | 174 | .92 | -- | .50 | 72,000(u) | 4600 |
| 23. | C.R. Steel 1018 | .050 | 490 | -- | -- | - | 60,000 | 3000 |

1 Relative tensile strength = tensile strength in psi x thickness

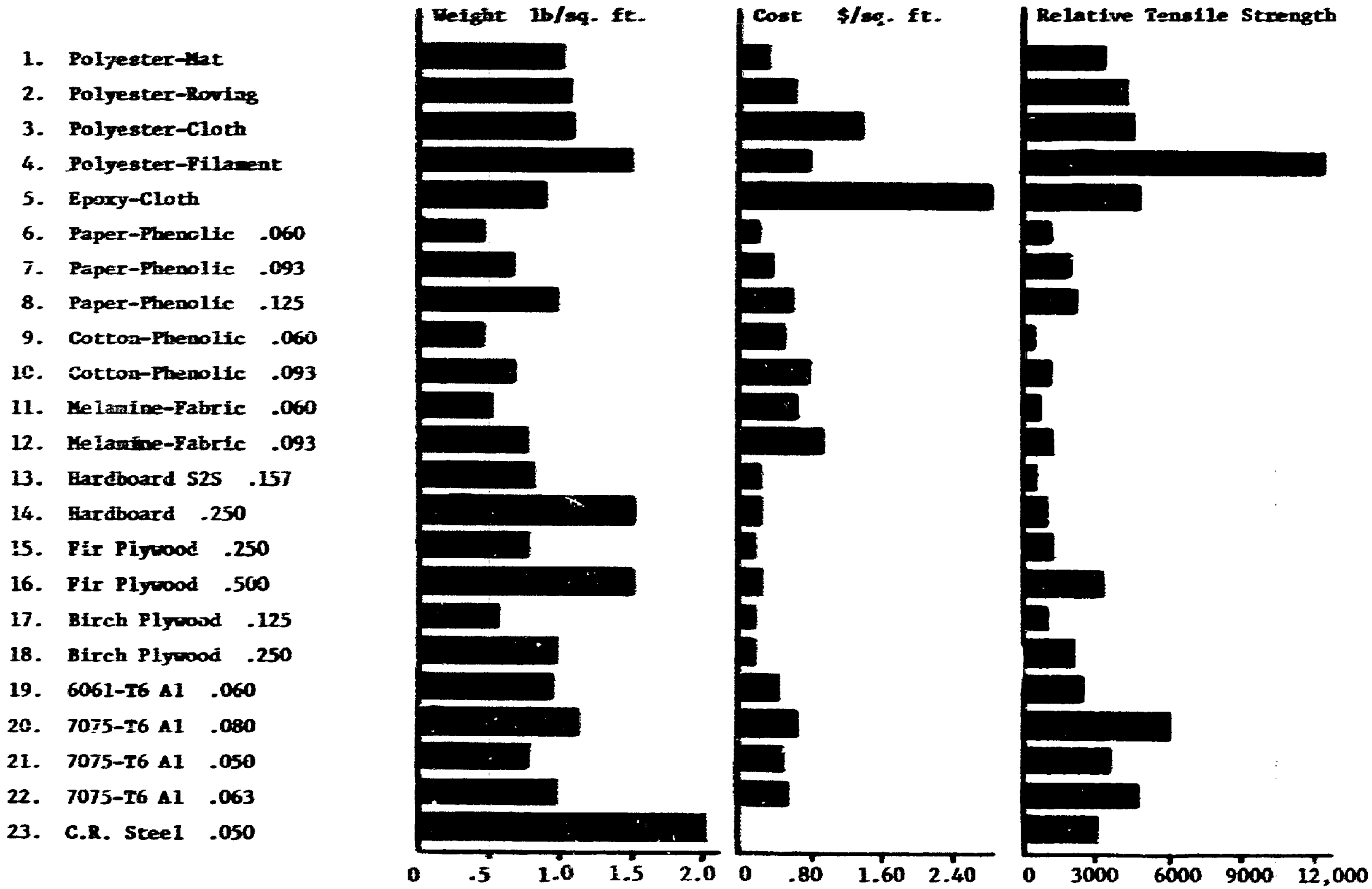



TABLE VIIA

BAR GRAPHS - PROPERTIES OF FACING MATERIALS

TABLE VIIB

STRENGTH, COST, WEIGHT RELATIONSHIPS OF SKIN MATERIALS

| | Material | Relative Strength / Wt. per sq. ft. | Relative Strength / Cost per sq. ft. | Relative Strength / Wt. x cost |
|---|---|---|---|---|
| 1. | Polyester/fiber glass 4-oz. mat 1 layer 181 cloth | 31 | 89 | 89 |
| 2. | Polyester/fiber glass Woven roving | 36 | 73 | 66 |
| 3. | Polyester/fiber glass 8-ply, 181 cloth | 39 | 34 | 30 |
| 4. | Polyester/fiber glass filament-wound | 83 | 166 | 111 |
| 5. | Epoxy/fiber glass FR-45 | 53 | 18 | 20 |
| 6. | Paper/phenolic Formica S-52 | 27 | 50 | 114 |
| 7. | Paper/phenolic Formica S-52 | 27 | 51 | 74 |
| 8. | Paper/phenolic Micarta | 25 | 43 | 48 |
| 9. | Cotton/phenolic Formica CN | 15 | 14 | 32 |
| 10. | Cotton/phenolic Formica CN | 16 | 15 | 22 |
| 11. | Melamine/fabric Formica Q236 | 16 | 13 | 27 |
| 12. | Melamine/fabric Formica Q236 | 16 | 13 | 18 |
| 13. | Tempered hardboard Abitibi S25 | 8 | 68 | 88 |

TABLE VIIB(Continued)

| Material | Relative Strength / Wt. per sq. ft. | Relative Strength / Cost per sq. ft. | Relative Strength / Wt. x cost |
|---|---|---|---|
| 14. Tempered hardboard Masonite | 7 | 50 | 33 |
| 15. Fir Plywood | 18 | 105 | 140 |
| 16. Fir Plywood | 20 | 155 | 103 |
| 17. Birch Plywood | 16 | 67 | 112 |
| 18. Birch Plywood | 20 | 128 | 142 |
| 19. Aluminum 6061-T6 | 26 | 58 | 64 |
| 20. Aluminum 7075-T6 | 51 | 102 | 90 |
| 21. Aluminum 7075-T6 | 50 | 80 | 110 |
| 22. Aluminum 7075-T6 | 50 | 92 | 100 |
| 23. C.R. Steel 1018 | | | |

In the strength/cost ratios, the polyester-glass mat laminate, the filament-wound polyester, the one-quarter inch and one-half inch fir plywood and one-quarter-inch fir plywood appear competitive with aluminum. The important factor regarding the strength/cost ratio of the polyester-mat laminate and the filament-wound polyester is the fact that the cost figures for these materials are based on materials costs only. If fabrication costs are added, the ratios would be less favorable. Although the plywood has a good strength/cost ratio, it is not suitable for use as a facing material because of poor weather resistance, dimensional instability and lack of indentation resistance.

When relative strenght/weight x cost is considered, the polyester-glass mat laminate, filament-wound polyester, .060" phenolic-paper laminate, .157" tempered hardboard, and fir and birch plywood appear competitive with aluminum. However, the polyester-glass mat laminate, filament-wound polyester and plywood must be ruled out for reasons previously cited in comments on relative strength, strength/weight and strength/cost ratios. The .060" phenolic-paper laminate and .157 tempered hardboard have insufficient strength in these thicknesses, and when thickness is increased the strength/weight x cost figure no longer approaches that for aluminum.

The figures in Table VII thus indicate the superiority of the 7075-T6 aluminum alloy over the non-metallic materials. It should be noted also that problems of static discharge would probably be encountered with many of the non-metallic materials, although these could be eliminated by various techniques such as use of conducting paint, embedding a metal screen in the surface, or laminating metal foil to the surface. However, each of these modifications will involve some increase in cost and may be undesirable for other reasons.

Polyester-Fiber Glass Laminates

Glass fiber-reinforced polyester resins have a number of characteristics to recommend them as facing materials. They have good resistance to impact, roller indentation and fatigue, weather, and permanent deformation, and they are readily available at relatively low cost. They also present the possibility of decreased processing cost and elimination of adhesive cost through fabrication of the skin in place on the core material.

The disadvantage of polyester-fiber glass faces include problems in quality control, differences in thermal expansion coefficients between polyester-fiber glass faces and the edge extrusions and problems of bonding faces to edge members.

The polyester-fiber glass faces with which Arthur D. Little, Inc., has experimented consist of 4 ounces per square foot of 2-inch chopped-strand glass mat and a surface layer of Style 181 glass cloth. This laminate is about 1/8-inch thick and weighs about 1 lb. per square foot. Arthur D. Little, Inc. initial data on this face construction in our first progress report indicated a tensile strength 18,000 psi. Since that time we have found that tensile strengths in the range of 25,000 psi can be achieved with this type of laminate. Materials cost is about $.35 per pound.

There are several other possible constructions of reinforced polyester resin that have higher strength, but they are also higher in cost and weight. These constructions utilize woven glass roving and glass cloth as reinforcements. Filament-wound mat has very high strength but is not commercially available.

The following paragraphs describe in greater detail the fabrication methods, alternate construcrion and over-all disadvantages of polyester-fiber glass faces.

The polyester-fiber glass faces can be fabricated in place or premolded. In the fabrication--in-place or wet-layup technique, the polyester resin acts as the adhesive to bond the face to the core, and no additional adhesive is required in making the basic sandwich structure. If a honeycomb core material is used, there is an additional advantage in that the wet-layup technique will provide excellent filleting which will produce a better bond between the honeycomb core and the face then could be achieved with normal amounts of adhesive.

In the wet-layup fabrication procedure, we visualize the polyester faces being laid up on release plates. In this process the catalyzed polyester resin is spread on to a surface, the cloth is laid on the resin, and the air bubbles are rolled out of the resin-saturated cloth with special rollers. Additional resin is then applied, and the mat is laid over it and saturated by a similar rolling operation. After the layup of both faces is completed on separate release sheets, the core is sandwiched between the faces, and they are clamped in a jig for the necessary cure period.

In lieu of construction of some full-size panels, time cycles and therefore process costs cannot be determined exactly. We estimate that the use of the wet-layup technique to make a polyester-glass mat paper honeycomb sandwich would yield an over-all cost lower than a comparable paper honeycomb - aluminum face sandwich in which adhesive is required to bond the honeycomb and aluminum together.

If the wet-layup technique were to be used in fabrication of these panels, considerable though would have to be given to the techniques and procedures for incorporating the aluminum edge extrusions into the structure. It is possible that the edge extrusions could be bonded to the faces simultaneously with the curing of the wet layup, but considerable process development would be necessary.

The polyester-glass mat specimens could also be premolded. If this is done, additional adhesive would be required in order to bond the faces to the core, and the economies of a direct wet-layup fabrication would be lost. It appears that the overall cost of the sandwich panel would be equal to or slightly greater than an aluminum-paper honeycomb panel at equal strength.

With either the wet-layup or premolding technique using a mat laminate, the strength-weight ratio achieved is lower than 7075 aluminum alloy.

It would be possible to obtain higher strength by using a glass-cloth laminate instead of a glass-mat laminate. However, cloth is expensive, and the cost of such a facing would probably be \$2 - \$3 per square foot. The cloth laminate would have a lower strength-weight ratio than the 7075 aluminum alloy and it would be difficult to justify the additional cost for the laminate.

A woven roving laminate might also be used as a facing material, but again the cost would probably be higher than for an aluminum face of higher strength.

High strength structures can be made with glass-resinforced polyester by using more efficiently the strength of the glass fibers. One product of this type appears promising but is not yet commercially available. This product is made by a filament-winding technique. Resin-saturated glass roving is wound onto a large drum in a helical pattern. The winding is than cut longitudianlly at one point, peeled from the drum, and pressed to make a flat laminate. With a structure of this type, tensile strengths of 100,000 psi and higher can be achieved. However, a definite disadvantage to this type of structure in this application would be the problem of attachment of edge extrusions. The laminate would probably have little fastener holding power near the edges where the cut filaments would occur. Since this process is not being used commercially, we are not able to obtain any projected cost figures for it. However, we believe that the cost would be competitive with, or only slightly more expensive than the aluminum, and the structure would have an advantage in weight-strength ratio over aluminum.

There is another technique that would involve actual filament winding of the module. In this technique some type of aluminum extrusion which represents a portion of the over-all edge member configuration would be attached to the edges of the core material. Resin-saturated fiber glass roving would than be wound directly onto the panel core. The winding would be done in two directions successively in order to provide the desired two-dimensional strength orientation.

This process would provide maximum physical properties at minimum weight and would probably be one of the most efficient types of sandwich construction that could be used for this purpose. Following cure of the resin, the remaining portion of each edge member would be mechanically attached to the portion that is wound into the structure. In a face of this type, tensile strength in the range of 150,000 psi might be achieved.

We have also considered the use of metallic reinforcing filaments in laminates but these do not present any great advantage in cost or performance at the present time.

Apart from strength, cost, and weight relationships, there is an important factor that one must consider in connection with the use of glass-reinforced resin faces, particularly with the wet-layup technique. This factor is quality control. The reinforced-plastics industry is not yet sufficiently advanced technically to specify resins, reinforcements, and laminates in the exacting way that metal alloys are specified. Part of the problem in quality control of wet-layups is the fact that fabrication techniques as well as raw materials used can have a substantial effect on properties of the finished laminate. These quality control problems do not rule out the use of reinforced plastic faces, but they do represent another factor that should be seriously considered in connection with the selection of facing materials.

Another disadvantage of the polyester fiber glass faces is the difference in thermal expansion coefficients between the faces and the edge extrusions which will presumably be aluminum. An exact thermal expansion coefficient cannot be specified for the reinforced polyester because the coefficient will depend on type, form, and percentage of glass used in the laminate. In general, the coefficient for these laminates is close to that of aluminum, but even small differences could effect pallet performance over the extreme temperature range that might be encountered in use.

A further disadvantage of polyester-glass fiber laminates as faces is the difficulty of attachment of faces to edge extrusions. Although satisfactory attachment probably could be achieved, very close process control would be necessary to assure a strong joint.

One additional disadvantage of the polyester-fiber glass laminates as facings is their resistance to permanent deformation. Although this characteristic is an advantage in some respects, it has also proved to be a disadvantage. The face may deflect sufficiently under load to cause permanent structural damage to the core and then return to its original position when it is unloaded so that there is no visual indication of the damage that has occurred. Under similar circumstances an aluminum face will dent or bend so that there is visual evidence of the internal failure.

Epoxy-Fiber Glass Laminates

Epoxy resin-fiber glass laminates might also be used as facing materials. They could be laid up wet and molded onto the core or molded separately and bonded to the core as with the polyester laminates. The epoxy laminates have slightly higher strength than the polyester laminates; however, the epoxy laminates would also cost more because the epoxy resins are 60 to 70 cents per pound, as compared to 20 to 30 cents per pound for the polyester resins. Since the epoxy laminates have many of the same basic disadvantages as the polyester laminates plus a cost disadvantage, we do not believe they represent good candidates for facing materials.

Laminates

High-pressure phenolic-resin laminates made with paper and with cotton cloth are commercially available and are used industrially for a number of purposes, including substantial use as electrical insulators. These laminates have good weather resistance, a fairly good strength-to weight ratio, and good impact resistance.

In our test program we have determined that phenolic-paper laminates such as Micarta made by Westinghouse, and Formica made by American Cyanamid, have excellent resistance to puncture and permanent indentation due to high roller loadings or roller fatigue. However, it appears that for the critical 9 G forward restraint condition, the strength of these laminates would be inadequate.

Melamine Laminates

Melamine resin laminates made with paper and cloth are commonly produced for decorative counter tops and also for industrial purposes. The melamine laminates have somewhat better water and weather resistance than the phenolics, but they are higher in cost and provide little or no advantage from the standpoint of tensile strength. Therefore, they do not appear to provide any important advantages as pallet face materials.

Hardboard

A number of types of hardboards are available. Some of them are very dense and appear to have good indentation resistance. However, we found in our testing program that the hardboard alone would not adequately withstand the puncture test. The hardboard would not have sufficient strength for use as a skin material, nor would it have adequate weather resistance. We have therefore considered the hardboard primarily as a backup layer for an aluminum or other facing material in order to provide improved load-spreading characteristics and panel stiffness. However, we have generally concluded from our tests that a five-layer structure of this type is not desirable since it would involve increased adhesive and processing costs with only a nominal increase in physical properties.

## Plywood

Plywood was also evaluated as a face material but it does not have the required weather resistance, impact resistance, and indentation resistance. It was therefore considered primarily for use in conjunction with a thin metal or reinforced plastic surface. Two types of plywood were evaluated; birch and fir.

Fir plywood is commonly used as a construction material and information is readily available on its physical properties. It does not have high tensile strength, but it does aid in increasing panel stiffness as indicated by initial beam load-deflection tests. The true value of fir plywood as a backup face material can be determined only on a full-size prototype where the effect of the plywood on panel stiffness and its other desirable effects can be fully evaluated. One such desirable effect might be stabilization of the aluminum face. If the aluminum tends to work and elongate when passing over the conveyors under load, fir plywood bonded to the aluminum with a thermosetting adhesive might help to reduce the elongation. The structural advantages of such a 5-ply laminate would have to be carefully weighed against the increased cost and weight of such a construction and it does not appear promising at the present time.

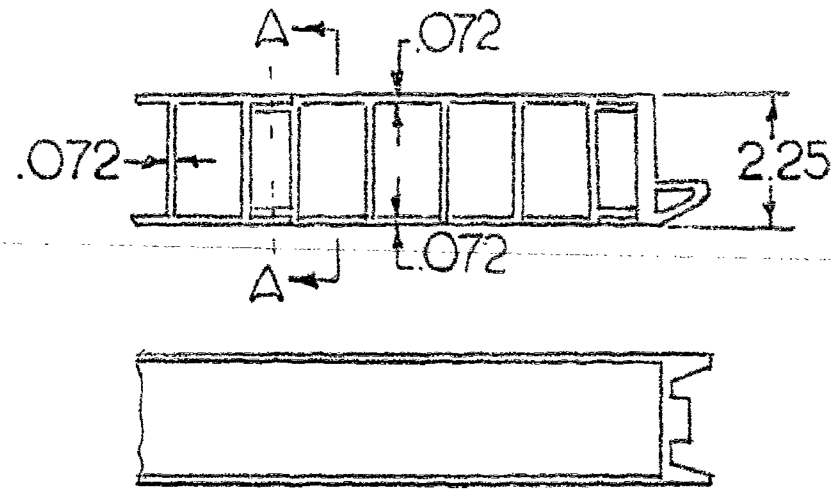
Birch plywood is not used widely for structural purposes; it is used primarily as a decorative material and structural properties are not controlled or specified as well as they are with fir plywood. The birch plywood might be used in the same manner as the fir plywood, but it is not as desirable due to the lower degree of quality control.

## Recommended Facing Material

7075-T6 aluminum alloy has been selected for the facing material on the basis of its excellent strength, weight and cost relationships.

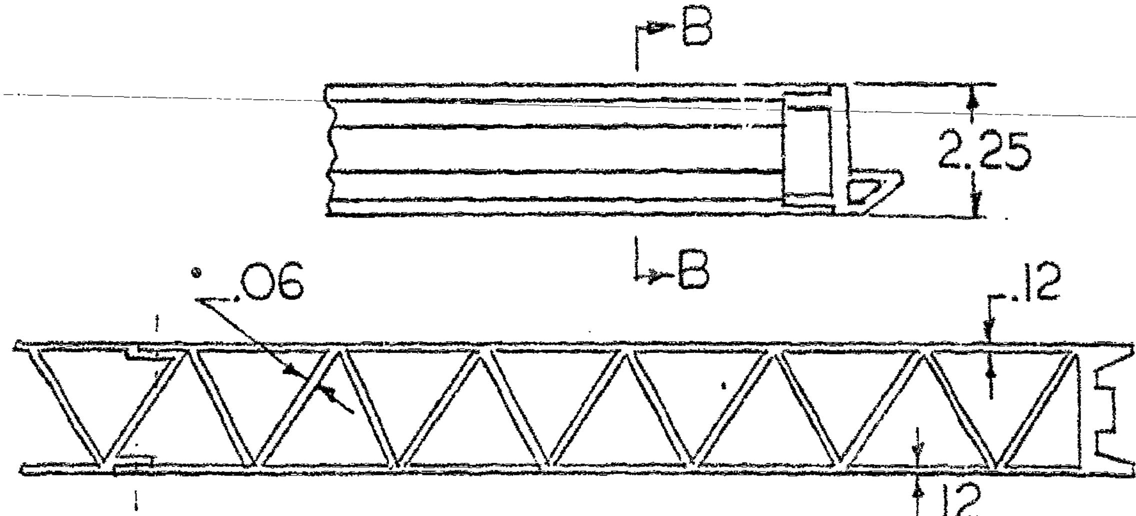
TECHNICAL ANALYSIS FORM

| | | |
|---|---|---|
| BY ENAFFA DATE 6-18-65 | BROOKS & PERKINS | SHEET 56 OF |
| CK. DATE | b-p | SUBJECT |
| REV. DATE | DEFENSE PRODUCTS DIVISION | |




SEC. A-A
WT./SQ.FT.= 4.25 LB.

"FIG.4a"




SEC: B-B

WT./SQ.FT. = 5.38 LB.

"FIG.4.b"

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## Integral Core and Facing Material

Figures 4a and 4b illustrate two types of aluminum extrusion proposed for pallet construction.

Figure 4a has excellent undirectional strength characteristics. The logistics pallet, however, requires a structure with bi-directional strength properties, (ref: page 32). Therefore this section has been eliminated because of non-applicability.

Figure 4b illustrates a much improved section of an aluminum extrusion. The diagonally oriented webs provide a truss-like structure capable of transmitting shear forces laterally and longitudinally. The thicknesses of the flange and web portions of the extrusion have been designed from the anticipated loadings on the Universal Platform. 6061-T6 material has been selected because of its good extrudability. To achieve maximum reuseability via minimizing structural deformation that may occur during the severe random ground impacting of the LAPES platform, the allowable calculated stress level has been limited to 18,000 psi. This assumed allowable stress provides a 50% margin of safety between the anticipated actual stresses and the proportional limit of 6061-T6.

An aluminum extrusion, similar to this, is now being evaluated under another Air Force contract. Scheduled air-drop with the next few months will indicate its adaptability for low level air delivery missions. Its weight of 5.38 pounds per foot eliminates it from consideration when attempting to incorporate this design into a light weight logistics pallet.

## Composite Structure

A large number of composite structures have been made up and tested using virtually all combinations of facing and skin materials that have been described in this report. As was previously noted, the tests on these panels indicate that the most promising structures based on materials that are now commercially available consist of impregnated - paper honeycomb core and 7075-T6 aluminum faces. The test results for the various constructions are shown in Table 7C. The following paragraphs of this section describe the test procedures and the test results for each specimen. Table VIII gives some comparative cost and weight data on honeycomb and balsa sandwich constructions.

## TABLE VIIC

## TEST RESULTS

| Sample No. | Composition | | Penetration Tests: Deflection at 750 psi, Initial | Penetration Tests: Deflection at 750 psi, Permanent | Penetration Tests: Yield Max Load (psi) | Penetration Tests: Deflection at Yield (in.) | Penetration Tests: Permanent Deflection (in.) | Roller Resistance Test 1000 lb load: Pull at 1000 lbs (lbs) | Roller Resistance Test 1000 lb load: Deflection Initial (in.) | Roller Resistance Test 1000 lb load: Deflection After 100 Pulls (in.) | Roller Identification Test 5000 lb load: Initial Deflection (in.) | Roller Identification Test 5000 lb load: Permanent Deflection (in.) | Beam Bending Test: Transverse Load (lb) | Beam Bending Test: Deflection of Load (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 99\|3/8\|25 Hexcel honeycomb, Aluminum | .063" | .015" | Nil | 1100 | 0.0196 | 0.047 | 4-initial | Nil | Nil | | | | |
| | Skins .063, & .080" Bonded with Epoxy | .080" | .015" | Nil | 939 | 0.0196 | 0.047 | 6-final | Nil | Nil | .009 | Nil | 1900 | .099 |
| 16 | 80\|3/8\|18 Hexcel honeycomb, Aluminum | .063" | .015" | Nil | 925 | 0.024 | 0.047 | 6 | Nil | Nil | .067 | .015 | | |
| | Skins .063, & .080" Bonded with Epoxy | .080" | .015" | Nil | | | | | | | .050 | .028 | 1900 | 0.110 |
| 17 | 99\|3/8\|25 Hexcel honeycomb, 1/4" plywood with .032" Aluminum Skins | | .013" | Nil | 1540 | 0.0196 | 0.047 | 6 | .003 | .001 | 0.047 | 0.0075 | 2540 | 0.149 |
| 18 | Balsa Core with Polyester-Glass Skins | | .000" | Nil | 5700 | 0.086 | 0.172 | 2 | Nil | Nil | Nil | Nil | 2640 | 0.099 |
| 19 | 80\|3/8\|18 Hexcel honeycomb Polyester-Glass Skins | 780 psi | .070" | Nil | 770 | 0.0196 | 0.187 | 20 | crushed | cracking | complete crushing at 2000 lb | | 1250 | 0.099 |
| 20 | 6 lb-ft$^3$ Urethane Foam Polyester-Glass Skins | | .109" | Nil | 770 | 0.222 | 0.375 | 14-18 | .009 | cracked | 0.281 | 0.065 | 330 | 0.079 |
| 21 | 99\|3/8\|25 Hexcel honeycomb 1/8" paper Micata Skins Bonded with Epoxy | | .015" | Nil | 1040 | 0.035 | 0.141 | 4 | Nil | Nil | Nil | Nil | 1900 | 0.118 |
| 22 | 6 lb-ft$^3$ Urethane Foam with Polyester-Glass Skins | | .125" | Nil | 990 | 0.148 | 0.313 | 14-18 | .005 | cracked | 0.344 | 0.088 | 1075 | 0.473 |
| 23 | 80\|1/2\|18 (UBC) honeycomb with Polyester-Glass Skins | | .125" | Nil | 330 | 0.036 | 0.015 | 6 | .018 | crushed | complete crushing at 1000 lb | | 327 | 0.078 |
| 24 | 80\|1/2\|18 (UBC) honeycomb filled with 1.5 lb-ft$^3$ Urethane Foam with Polyester-Glass Skins | | .015" | Nil | 925 | 0.039 | 0.015 | 4 | .005 | Nil | 0.348 | .060 | 1320 | 0.118 |
| 25 | 80\|1/2\|18 (UBC) honeycomb filled with 1.5 lb-ft$^3$ Urethane Foam with | .063" | .015" | Nil | | | | 2 | .003 | Nil | .003 | 0 | | |
| | .063, .080" Aluminum Skins | .080" | .015" | Nil | 1100 | 0.0197 | 0.047 | 2 | .003 | Nil | 0.189 | 0.037 | 1830 | 0.099 |
| 26 | 80\|1/2\|18 (UBC) honeycomb filled with 1.5 lb-ft$^3$ Urethane Foam 1/8" Paper Micata | | .015" | Nil | 1000 | 0.0197 | 0.000 | 0 | Nil | Nil | Sample failed at one end only. Due to soft spot in foam core. | | 2060 | 0.110 |
| 27 | 99\|5/16\|25 Hexcel honeycomb with 1/8" Paper Micata Bonded with Epoxy | | .015" | Nil | 1540 | 0.0284 | 0.000 | 2 | Nil | Nil | Nil | Nil | 1150 | 0.110 |
| 28 | 99\|5/16\|25 Hexcel honeycomb with .063", | .063" | .015" | Nil | 1760 | 0.0274 | 0.041 | | | | | | | |
| | .080" Aluminum Skins Bonded with Epoxy | .080" | .015" | Nil | 1900 | 0.0274 | 0.041 | 4 | Nil | Nil | Nil | Nil | 1520 | 0.118 |
| 29 | 99\|5/16\|25 Hexcel honeycomb with Polyester-Glass Skins | | .007" | Nil | 1200 | 0.023 | 0.000 | 6 | Nil | Nil | 0.218 | 0.030 | 1400 | 0.138 |
| 30 | Douglas Aircomb 125-35-20 .063", | .063" | .015" | Nil | 1980 | 0.0236 | 0.031 | | | | | | | |
| | .080" Aluminum Skins Bonded with Epoxy | .080" | .015" | Nil | 1980 | 0.0253 | 0.031 | 4 | Nil | Nil | .009 | Nil | 330 | .039 |
| 31 | 99\|3/8\|25 Hexcel honeycomb with .063" Aluminum Skins (7075T6) Bonded with Epoxy | | .015" | Nil | 2420 | 0.035 | 0.047 | 3 | Nil | Nil | Nil | Nil | 990 | .079 |
| 32 | 99\|3/8\|25 Hexcel honeycomb with .050" Aluminum Skins (7075T6) Bonded with Epoxy | | .015" | Nil | 1940 | 0.027 | 0.047 | 3 | Nil | Nil | Nil | Nil | 1650 | .138 |
| 33 | 99\|3/8\|25 Hexcel honeycomb with .063 & .050" (7075T6) Aluminum Skins Bonded | .063" | .015" | Nil | | | | | | | | | | |
| | with Rubber Cement | .050" | .015" | Nil | Insufficient Bond | | | 3 | Nil | Nil | Not Run (Poor Bond) | | Not Run | |
| 34 | Same as #30 | .050" | .015" | Nil | 1540 | 0.024 | 0.047 | | | | | | | |
| | | .063" | .015" | Nil | 1870 | 0.027 | 0.047 | 3 | Nil | Nil | Nil | Nil | 1400 | 0.157 |
| Control | Brooks-Perkins Balsa with Aluminum Skins | | .015" | Nil | 4300 | 0.165 | 0.196 | 4 | Nil | Nil | Nil | Nil | 3120 | 0.096 |



A

## TABLE VIIC

## TEST RESULTS

| | ...ration Tests | | Roller Resistance Test 1000 lb load | | | Roller Identification Test 5000 lb load | | Beam Bending Tests | | | Compression Test | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Deflection at Yield (in.) | Permanent Deflection (in.) | Pull at 1000 lbs (lbs) | Deflection Initial (in.) | Deflection After 100 Pulls (in.) | Initial Deflection (in.) | Permanent Deflection (in.) | Transverse Load (lb) | Deflection of Load (in.) | Permanent Deflection (in.) | Dry (psi) | Wet (psi) | % Retention |
| 16 | 0.0196<br>0.0196 | 0.047<br>0.047 | 4-initial<br>6-final | Nil<br>Nil | Nil<br>Nil | .009 | Nil | 1900 | .099 | 0.016 | 306 | 85.5 | 28% |
| 1( | 0.024 | 0.047 | 6 | Nil | Nil | .067<br>.050 | .015<br>.028 | 1900 | 0.110 | 0.016 | 296 | 82.5 | 28% |
| 31 | | | | | | | | | | | | | |
| 1( | 0.0196 | 0.047 | 6 | .003 | .001 | 0.047 | 0.0075 | 2540 | 0.149 | 0.031 | | | |
| | 0.046 | 0.172 | 2 | Nil | Nil | Nil | Nil | 2640 | 0.099 | 0.016 | 1350 | 1600 | 100% |
| 1( | | | | | | | | | | | | | |
| | 0.0196 | 0.187 | 20 | crushed | cracking | complete crushing at 2000 lb | | 1250 | 0.099 | 0.016 | 121 | 69 | 57% |
| | 0.222 | 0.375 | 14-18 | .009 | cracked | 0.281 | 0.065 | 330 | 0.079 | -- | 110 | 93 | 85% |
| 16 | 0.035 | 0.141 | 4 | Nil | Nil | Nil | Nil | 1900 | 0.118 | 0.016 | | | |
| i0 | 0.148 | 0.313 | 14-18 | .005 | cracked | 0.344 | 0.088 | 1075 | 0.473 | 0.250 | | | |
| | 0.036 | 0.0156 | 6 | .018 | crushed | complete crushing at 1000 lb | | 827 | 0.078 | -- | | | |
| .5 | 0.039 | 0.015 | 4 | .005 | Nil | 0.348 | .060 | 1320 | 0.118 | 0.015 | | | |
| i6 | 0.0197 | 0.047 | 2<br>2 | .003<br>.003 | Nil<br>Nil | .003<br>0.189 | 0<br>0.037 | 1830 | 0.099 | 0.016 | 410 | 344 | 85% |
| i6 | 0.0197 | 0.000 | 0 | Nil | Nil | Sample failed at one end only. Due to soft spot in foam core. | | 2060 | 0.110 | 0.016 | | | |
| 18 | 0.0284 | 0.000 | 2 | Nil | Nil | Nil | Nil | 1150 | 0.110 | 0.008 | | | |
| '8 | 0.0274<br>0.0274 | 0.041<br>0.041 | 4 | Nil | Nil | Nil | Nil | 1520 | 0.118 | 0.008 | 450 | 122 | 27% |
| 6 | 0.023 | 0.000 | 6 | Nil | Nil | 0.218 | 0.030 | 1400 | 0.138 | 0.016 | | | |
| 18 | 0.0285<br>0.0253 | 0.031<br>0.031 | 4 | Nil | Nil | .009 | Nil | 330 | .039 | Skin Delaminate | 580 | 165 | 28% |
| .6 | 0.035 | 0.047 | 3 | Nil | Nil | Nil | Nil | 990 | .079 | .016 | | | |
| .6 | 0.027 | 0.047 | 3 | Nil | Nil | Nil | Nil | 1650 | .138 | .016 | | | |
| | ...ficient Bond | | 3 | Nil | Nil | Not Run (Poor Bond) | | Not Run | | | | | |
| 6 | 0.024<br>0.027 | 0.047<br>0.047 | 3 | Nil | Nil | Nil | Nil | 2400 | 0.157 | 0.016 | | | |
| 6 | 0.165 | 0.196 | 4 | Nil | Nil | Nil | Nil | 3120 | 0.099 | 0.016 | | | |

## TABLE VIII

## COST AND WEIGHT DATA ON BALSA AND PAPER HONEYCOMB CONSTRUCTIONS

| | Core | Face | Wt/Sq. Ft | Cost/sq ft (Core & Face only) |
|---|---|---|---|---|
| 1. | Balsa | .080-inch 7075-T6 Al | 3.73 lbs. | $2.03 |
| 2. | 99/3/8/25 Hexcel paper honeycomb | .080-inch 7075-T6 al | 2.93 lbs. | 1.58 |
| 3. | Balsa | .050-inch 7075-T6 Al | 2.94 lbs. | 1.80 |
| 4. | 99/3/8/25 Hexcel paper honeycomb | .050-inch 7075-T6 Al | 2.11 lbs. | 1.40 |
| 5. | Union-Camp 80/1/2/18 paper honeycomb filled with 1.5 lb urethane foam | .050-inch 7075-T6 Al | 2.44 lbs. | 1.70 |
| 6. | 99/5/16/25 Hexcel paper honeycomb | .080-inch 7075-T6 Al | 2.93 lbs. | 1.64 |
| 7. | Style 125-35 type 20 Douglas Air-comb | .080-inch 7075-T6 Al | 2.88 lbs. | 1.68 |

## Puncture Test

In this test a 1 square inch pressure foot is pressed against the panel. The specifications require that after a 750-lb. loading has been applied with the 1 square inch pressure foot, the permanent deflection does not exceed .010 inch. In addition to the 750-lb. load, Arthur D. Little, Inc. also tested a number of panels to destruction using this procedure by increasing the load until the skin punctured or extensive core crushing occurred. Force and deflection at yield and permanent deflection after removal of the load were noted. In some cases loading was continued beyond yield to assure that there was no second load peak. In some of these cases the permanent deflection noted was higher than the deflection at yield. The test fixture used for the puncture test is shown in Figure 5.

## ROLLER-RESISTANCE TEST

In this test the specimen panel was placed between 2 sets of conveyor rollers. Force was then applied to the lower set of rollers through two large coil springs. The coil springs were necessary to allow the panel to be moved back and forth between the rollers under a constant load. Arthur D. Little, Inc. found that unless the springs were used, substantial variations in the load occurred due to small variations in panel thickness. The standard loading used in this test was 1,000 lbs. on the two rollers. This loading simulates a 10,000 lb. load on the pallet. In the test measurement was made of the force required to move the panel between the rollers. The panel was then moved back and forth 100 times and a second reading of force required to move the panel and surface deflection of the panel was made. This test was used as an indication of the roller fatigue characteristics of the sandwich construction. The test fixture is shown in Figure 6.

## ROLLER-INDENTATION TEST

This test was used to determine whether the 50,000-lb. loading specified in the Statement of Work would cause any permanent deformation of the panel which would prevent easy movement of the panel with a 10,000 lb load. A two roller section of conveyor was pressed against a panel with a 5,000 lb. load to simulate 50,000 lbs. on the entire pallet. The indentation and permanent deformation caused by the rollers was observed. The test set-up is shown in Figure 7.

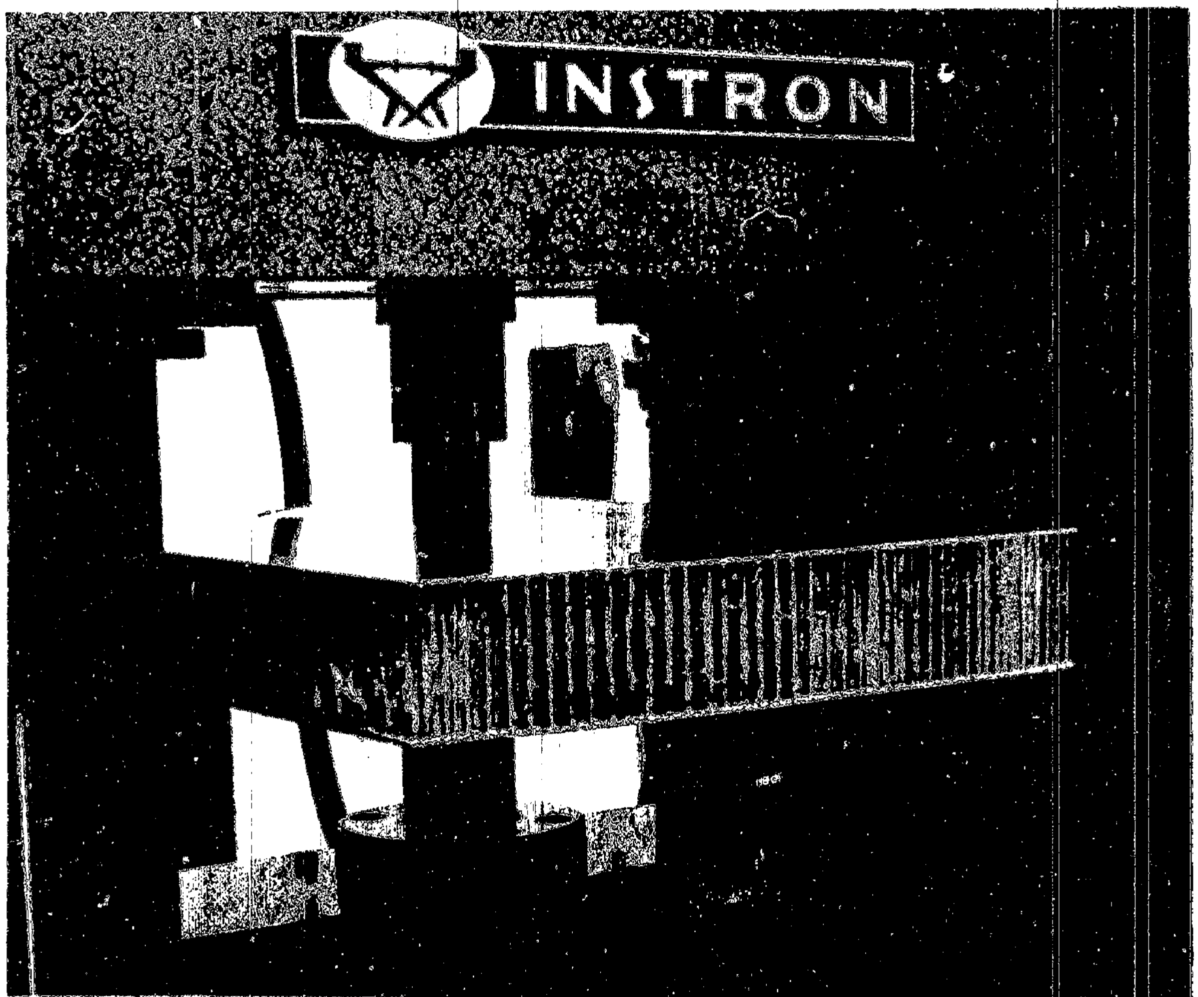



FIGURE 5 PUNCTURE TEST FIXTURE

Static-Bending and Deflection

Full scale beam deflection tests were not run as a part of this phase of the program. Attempts were made to run some beam strength tests using short beam sections 12 inches long by 4 inches wide. Because of the short span used, most of these tests produced core failure. There are some unexplained inconsistencies in the results, but general comparisons can be made. The test fixture is shown in Figure 8.


FIGURE 6 ROLLER RESISTANCE TEST FIXTURE

Compression Tests

These tests were conducted primarily to obtain some comparative results in showing the effect of liquid water on the various core materials. The tests were conducted on two inch square panel specimens. Water exposure was simulated by actually immersing these testing specimens in water overnight and then testing them in compression. This is an unusually severe test because it exposes a very large surface area of the core to water around the entire periphery of the 2 inch square. In the event of water leakage into a panel due to puncture of the facing material, or leakage along an edge, the water would be initially confined to those cells directly exposed to the leak or puncture, and the water would permeate only slowly into other cells.

## TEST RESULTS

### Specimen Number 15

The sample was composed of 99/ 3/8 /25 Hexcel honeycomb and skins of .063-inch 6061-T6 and .080-inch 7075-T6 aluminum bonded to the core with an epoxy-Versamid adhesive. The 750-psi deflection test produced no permanent deformation on either face. The penetration test to destruction showed 1100 psi for the .063-inch skin and 900 psi for the .080-inch skin. This discrepancy might be accounted for by several causes. The most probably cause is excess epoxy adhesive which ran down the core and stiffened the area where the .063-inch skin was tested. In the roller resistance test at 1000-lb. loading, no deflections were noted, and force required was 4 - 6 lbs. Very little deflection was noted on the 5000-lb. roller indentation test with no permanent deflection. The beam-bending test showed good strength with low deflection. Failure occurred only in the core. The compressive-strength test was approximately 300 psi dry, but only 28% of the strength was retained in the wet tests.

### Specimen Number 16

This sample was similar to 15 except that 80/ 3/8 /18 honeycomb was used in place of the 99/ 3/8 /25. The results with this honeycomb were surprisingly good. However. Arthur D. Little, Inc. encountered considerable difficulty with the epoxy- Versamid adhesive, which was not sufficiently thixotropic, running down the cell walls. This adhesive undoubtedly strengthened the honeycomb above its normal level so that it compared favorably with

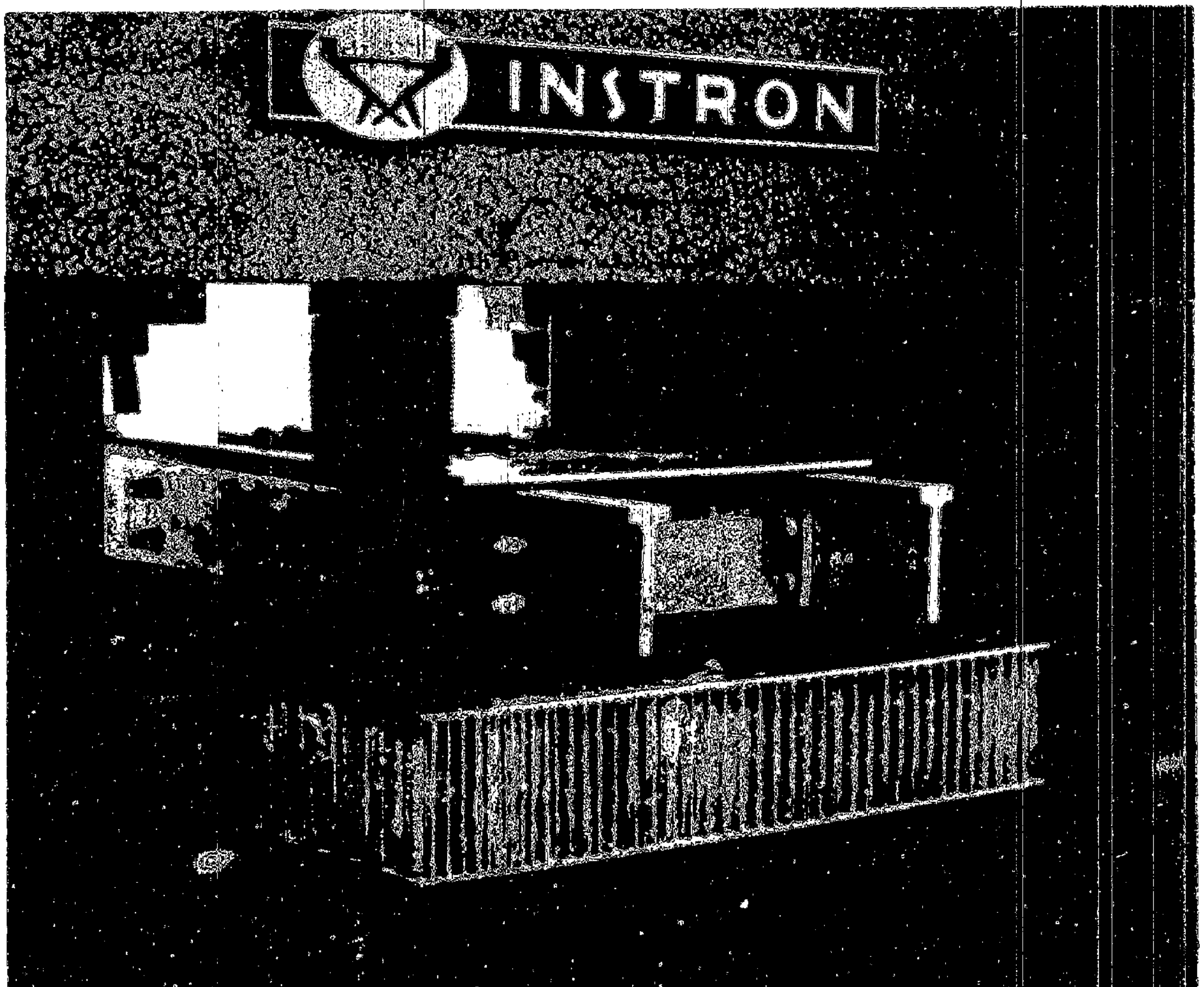



FIGURE 7 ROLLER INDENTATION TEST FIXTURE

specimen 15 in all tests except the 5,000-lb. roller indentation test where there was a very measurable permanent deflection. Again, high strength loss was noted in the wet compression test.

Specimen Number 17

This specimen consisted of the 99/ 3/8 /25 Hexcel honeycomb with a one-fourth inch fir plywood and .032-inch 6061-T6 aluminum skins bonded with epoxy-Versamid adhesive. This specimen showed high ultimate penetration and bending stiffness. However, permanent deformation was noted in both the roller resistance and indentation tests.

Specimen Number 18

This panel consisted of a balsa core with polyester-glass skins laid up on the balsa. All test results were high with this panel. It is interesting to note that the balsa apparently gained a little strength in the wet compression test.

Specimen Number 19

This panel consisted of 80/ 3/8 /18 Hexcel honeycomb with polyester-glass faces laid up in place. This specimen proved completely unstaisfactory in the roller resistance and indentation tests.

Specimen Number 20

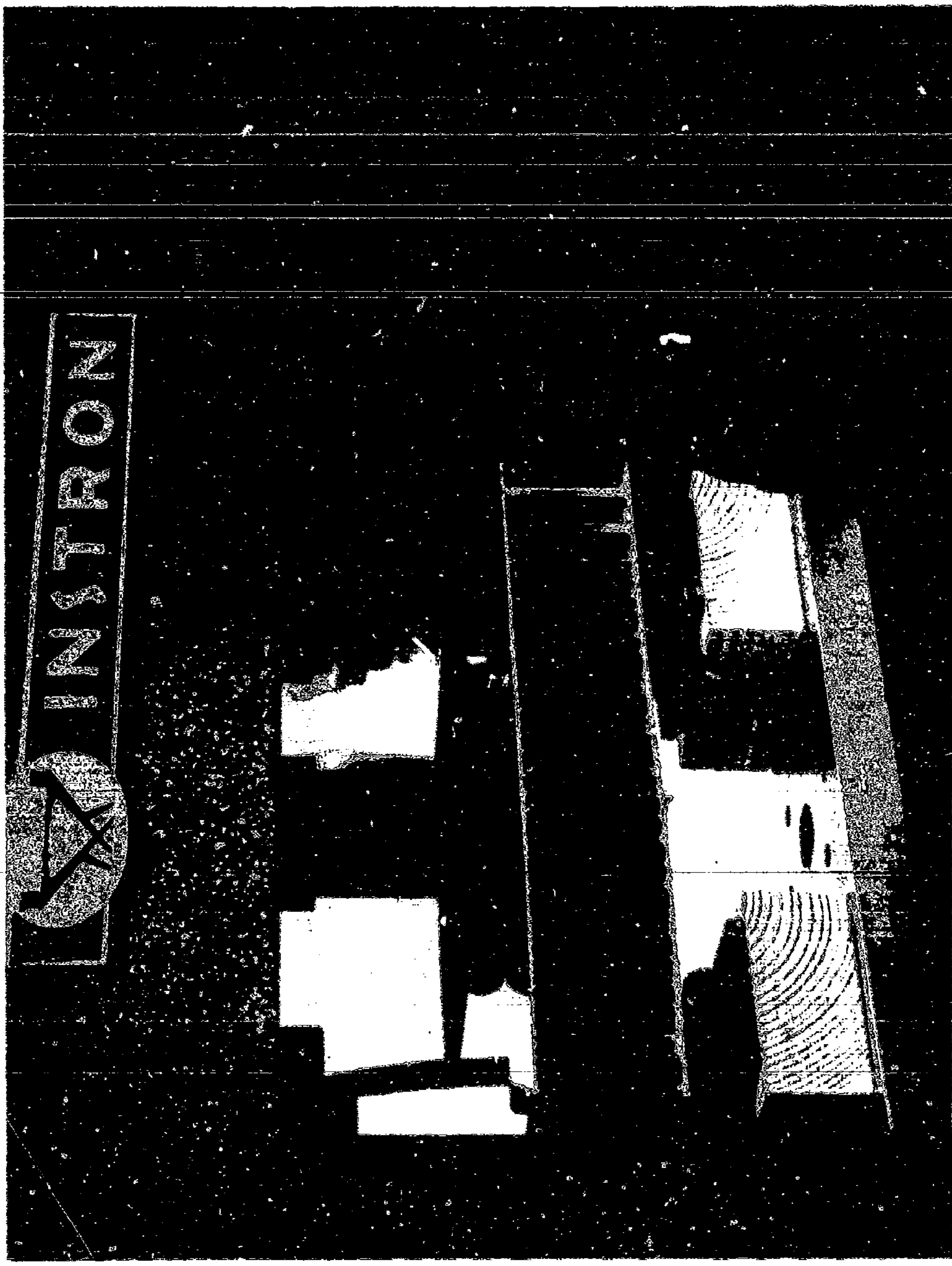
This specimen was a 6-lb. urethane foam faced with polyester-fiber glass skins laid up on the foam. Deflections in all tests were rather high and delamination of the skin occurred in the roller resistance test. A relatively high strength retention (85%) was noted in the wet compression test.

Specimen Number 21

This panel consisted of 99/ 3/8 /25 Hexcel honeycomb with 1/8-inch paper Micarta skins bonded with epoxy-Versamid adhesive. The test results are uniformly good, but calculations show that the tensile strength of the skins would be inadequate under the 9 G forward restraint loading.

Specimen Number 22

This panel consisted of 6-lb. urethane foam with polyester skins, and is generally comparable to panel 20.




FIXTURE 8 BEAM DEFLECTION TEST FIXTURE

Specimen Number 23

This specimen was made with 80/ 1/2 /18 Union-Camp honeycomb with polyester-glass skins laid up in place. This specimen proved unsatisfactory in the roller resistance and indentation tests. The panel also pointed up the problem of quality control, with the polyester skins, even on a test basis. In one portion, the panel satisfactorily passed the 750-psi deflection test while in another area of the panel a yield point was noted at 330-lb. loading, and a permanent deflection resulted.

Specimen Number 24

This specimen was made with 80/ 1/2 /18 Union-Camp honeycomb filled with a 1.5 lb urethane foam with polyester-fiber glass skins laid up in place. This panel showed unsatisfactory deformation in the roller indentation test.

Specimen Number 25

This specimen was made with 80/ 1/2 /18 Union-Camp honeycomb filled with 1.5 lb urethane foam with .063-inch 6061-T6 and .080-inch 7075-T6 aluminum skins bonded on with epoxy-Versamid adhesive. These test results were generally satisfactory with the exception of the slightly high permanent deflection sustained in the roller indentation test. The high dry and wet compressive strengths of the panel are notable. The use of the urethane foam increased the dry compressive strength more than 100%, and the loss in the wet test was only 15%.

Specimen Number 26

This specimen was made with 80/ 1/2 /18 Union-Camp honeycomb filled with 1.5 lb urethane foam. The faces were 1/8-inch paper Micarta bonded on with an epoxy-Versamid adhesive. The test results in this panel were generally favorable except for the 5,000-lb roller indentation test in which the sample failed due to non-uniform foaming into the core on one end of the panel.

Specimen Number 27

This panel was made with 99/ 5/16 /25 Hexcel honeycomb with 1/8-inch paper Micarta faces bonded with epoxy-Versamid adhesive. The test results on this specimen were uniformly good.

Specimen Number 28

This panel was made with 99/ 5/16 /25 Hexcel honeycomb with .063-inch 6061-T6 and .080-inch 7075-T6 aluminum skins bonded with epoxy-Versamid adhesive. These test results are generally very favorable with the exception of the substantial strength reduction that occurred in the wet compressive-strength tests. Strength retention was only 27%.

Specimen Number 30

This panel was made with Douglas Aircomb Style 165 -35 type 20 with .063-inch 6061-T6 and .080-inch 7075-T6 aluminum skins bonded with epoxy-Versamid adhesive. The test results on this panel were generally good except in the static-bending test where a faulty bond on one of the skins caused poor results. The very high dry compressive strength of 580 psi is noteworthy. However, the retention on wet test was only 28%.

Specimen Number 31

This specimen was made with 99/ 3/8 /25 Hexcel honeycomb with .063-inch 7075-T6 aluminum skins bonded with epoxy-Versamid adhesive. These results were uniformly good except for the static-bending tests where low strength was recorded apparently due to poor bond and excessive drainage of adhesive from the upper skin.

Specimen Number 32

This panel was made with 99/ 3/8 /25 Hexcel honeycomb with .050-inch 7075-T6 aluminum skins bonded with epoxy-Versamid adhesive. The test results were very good. The static-bending results were slightly low, but again, some bond failure due to excessive adhesive drainage was noted.

Specimen Number 33

This panel was made with 99/ 3/8 /25 Hexcel honeycomb with .063-inch and .050-inch 7075-T6 aluminum skins bonded with Pliobond contact cement. An inadequate bond was developed with this particular contact cement, and the test results were generally unsatisfactory.

Specimen Number 34

This specimen was made with Douglas Aircomb and was identical to specimen number 30. This duplicate was prepared in order to obtain a better bond and a better evaluation of the static-bending characteristics. The high-bending strength is noteworthy.

Control Specimen

This panel was made by Brooks & Perkins, Inc. with balsa core and aluminum skins to simulate the construction of the currently used 463L pallets and modular airdrop platforms. The uniformly high test results are generally superior to any of the other panels.

# SECTION VII

## UNIVERSAL PLATFORM DESCRIPTION

Primary emphasis was placed throughout the study on the development of a single sized module to comply with paragraph 4.3 of ASNLM Exhibit 63-6 which says in part - "All modules must be the same size".

Compliance with that requirement limits the choice of module sizes to 44 x 54, 54 x 88, 44 x 108, or 88 x 108". The ratings of each of these sizes was discussed in detail in Section V. Sketch Modules A, B, C, and D on which the cost and weight data in Section V was based are shown in figures, 9, 10, 11, 12 and 13. The 44" x 108" module is the most desirable size when we limit the selection to only one size.

Figure 9 illustrates the four (4) 44" x 54" modules assembled into an 88" x 108" logistics pallet. Each module consists of aluminum alloy extruded edge members, paper honeycomb core, and aluminum alloy skins all bonded and safety-riveted into an integral unit. Two adjacent edges are male configuration; the other two edges are female. The panels may be reversed - top to bottom. Female and male edge members, each 88" x 108" long are notched to correspond to the indent configuration of the 463L pallet. Cargo restraint tie-down rings, 10,000 pound capacity, are a part of the peripheral edge sub-assembly. Six rings are located to correspond to the hooks and keepers on the cargo restraint device described in Section X. The four modules, two 88" long edge sub-assemblies and two 108" long sub-assemblies are tongue and grooved together and pinned securely with a series of roll-pins or similar locking hardware.

This 44" x 54" module size has been rejected because of -

a. Excessive structural weight.

b. Excessive number of different extrusion configurations (male and female) and lengths (54", 88", 108" and multiples of 44" - of edge members necessary to adapt this small module into half-size logistics, full-size logistics, and various lengths of air-drop platforms.

c. Inherent weakness inducted by having both longitudinal and lateral joints.

d. High production costs.

Figure 10, illustrates two 54" x 88" modules assembled with separate edge sub-assemblies into an 88" x 108" logistics pallet. Except for the size of the basic module, the design is basically the same as for the 54" x 44" module. Two adjacent edges of the module would have male edges; the other two edges female. Male and female edge sub-assemblies, 88" x 108" long, are required to adapt the module edge to the 463L restraint rail configuration. Adaption of the 54" x 88" module into an air-drop platform 108" wide requires a family of longitudinal edge sub-assemblies in multiples of 88" long.

This 54" x 88" module has been rejected because of -

a. Excessive structural weight.

b. Excessive number of male and female edge members that must be furnished in 108" and multiples of 88".

c. Inherent weakness induced by having the longitudinal joing at the maximum bending stress point o f the pallet.

d. High production costs.

e. Excessive cubage loss in the aircraft when air-drop platform lengths vary in increments of 88".

Figure 12 illustrates an 88" x 108" module with separate edge members. All four sides of the module have a female edge member. Both the 88" and 108" long edge members are of the male configuration and are furnished complete with tie-down rings. This modular panel is also reversible. A family of longitudinal edge members, in increments of 88" could be provided to adapt this module to 108" wide air-drop platforms.

This 88" x 108" module has been rejected because of -

a. Excessive structural weight.

b. Excessive cubage loss in the aircraft when the air-drop platform lengths vary in increments of 88".

c. Limited ground mobility and handling care.

Figure 11 illustrates the one module size Universal Platform. Two modular panels (Nominally 44" x 88"), two identical 88" long edge member sub-assembly complete with tie-down rings, one each male and female 108" long edge member sub-assembly, and an appro - priate number of roll-pin type pins join into a full size 88" x 108" logistics pallet. Each of the panels may be reversible.

Each panel has .063 7075-T6 aluminum alloy sheet bonded to 99/ 3/8 /25 resin impregnated paper honeycomb core and 6061-T6 aluminum alloy extruded edge members. One of the 108" long edges is male configuration; the other three edges are female. The tongue and groove matching of the 108" long sides reacts the shear and bending moment forces which occur at mid-open of the assembled platform. Pins, located approximately six inches apart react the tension forces at the joint.

Each of the edge member assemblies, extruded from 6061-T6 aluminum alloy material, and notched to comply with the standard 463L pallet edge configuration, includes six (6) 10,000 pound capacity tie-down rings. The rings are located to correspond to the hook spacing of the cargo restraint device. Bending moments and shear forces between the edge members and panels are reacted by fit of the mating members.

Air drop platforms, 108" wide, may be assembled by joining the 44" x 108" module with a family longitudinal edge members varying in length by44 inches. Platform lengths of 82", 123", 164", 205", 246", and 287 inches long may be made. 10,000 pound capacity tie-down rings may be spaced at 10 inch or 6 inch increments.

Although the 44" x 108 inch module would comply the stated objectives of the Universal Platform Statement of Work, the estimated costs and weights of both the logistics and air-drop configurations would be substantially greater than the present costs of the pallets and modules now in service.

TECHNICAL ANALYSIS FORM

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|---|---|---|
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| REV. ___ DATE ___ | DEFENSE PRODUCTS DIVISION | |

LOGISTICS PALLET MADE UP OF (4) 44" x 54" MODULES

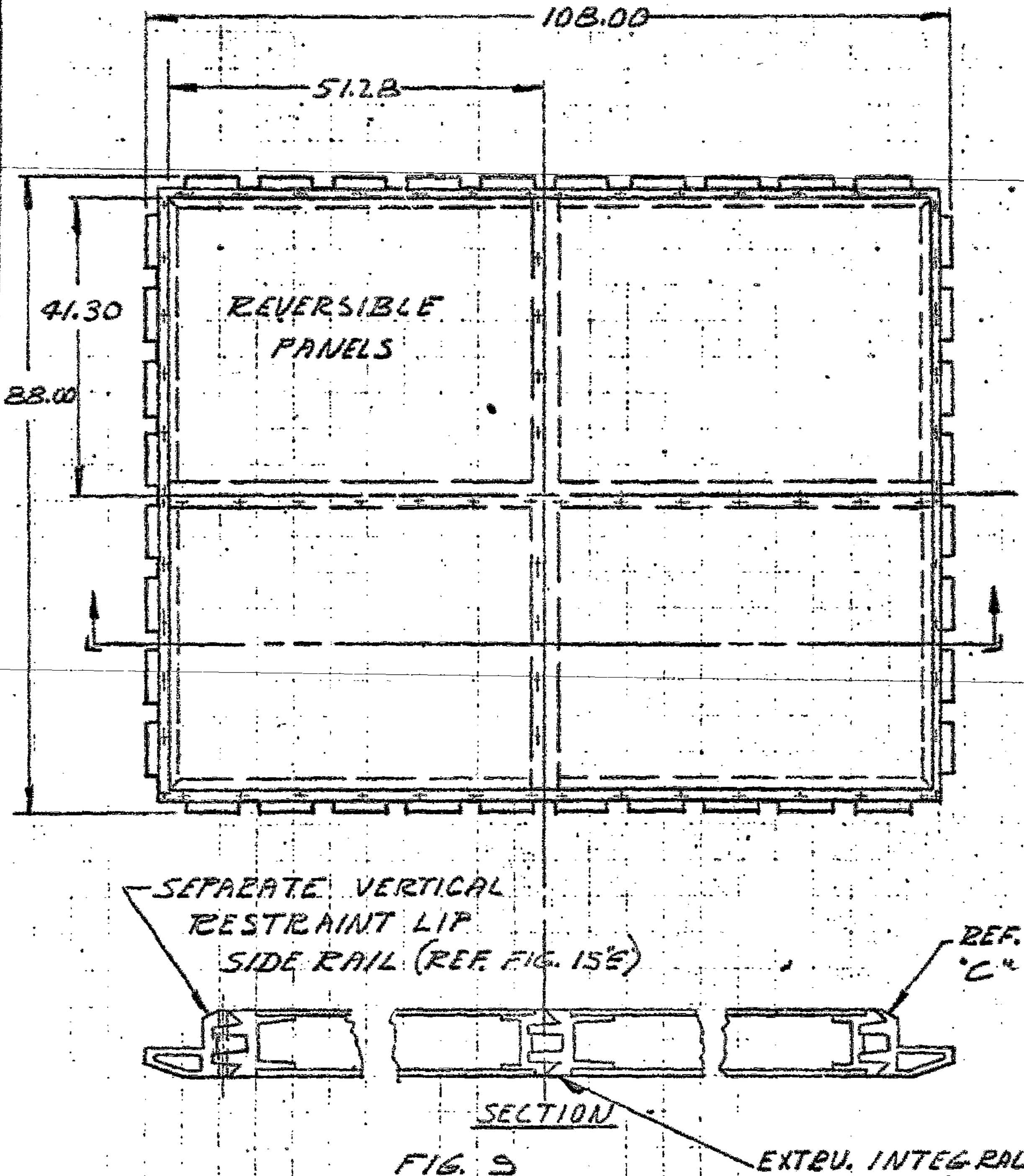


FIG. 9



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| REV. ____ DATE ____ | DEFENSE PRODUCTS DIVISION | |

LOGISTICS PALLET MADE UP OF (2) 54" x 88" MODULES

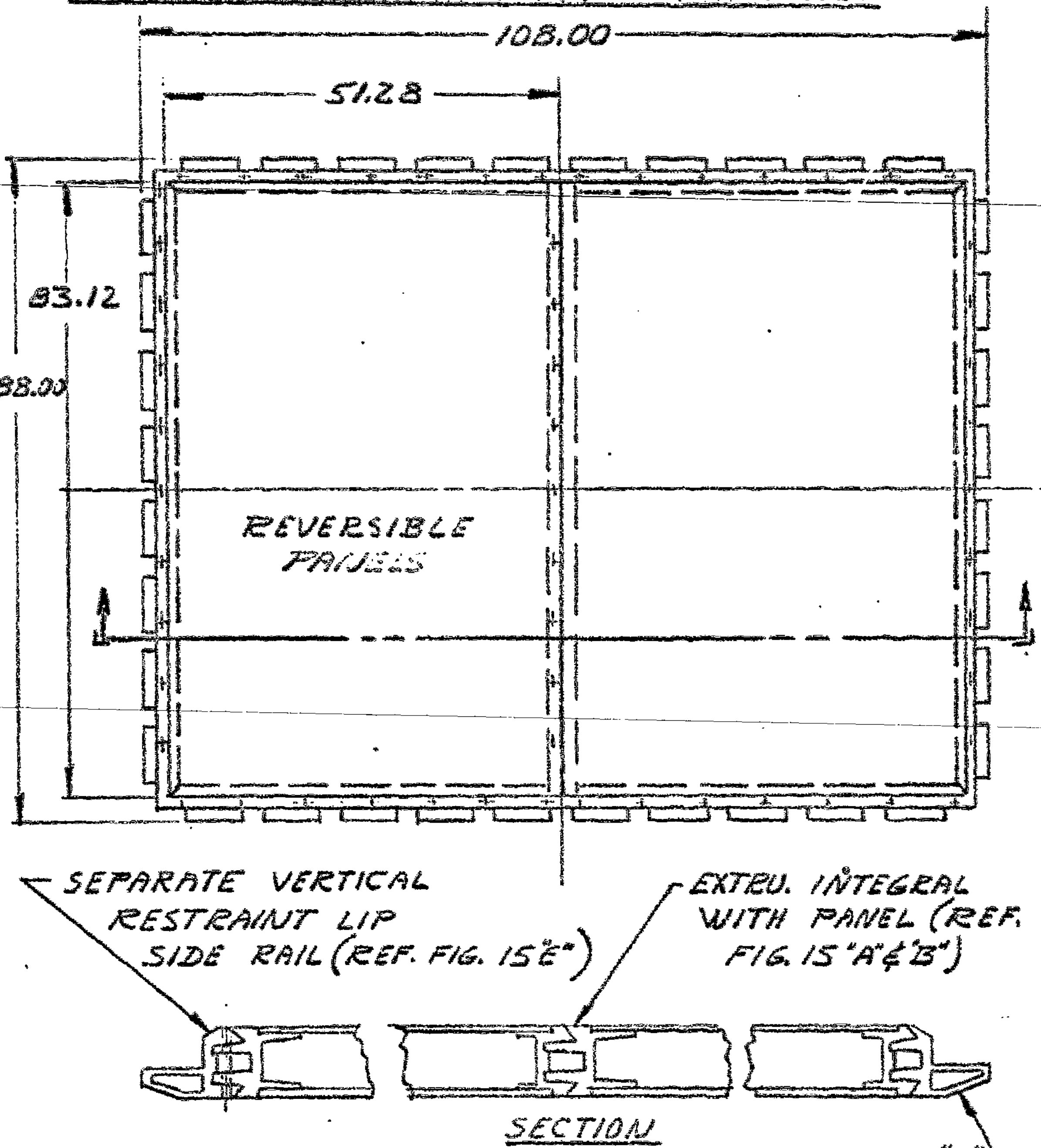


FIG. 10



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LOGISTICS PALLET MADE UP OF (2) 44" x 108" MODULES

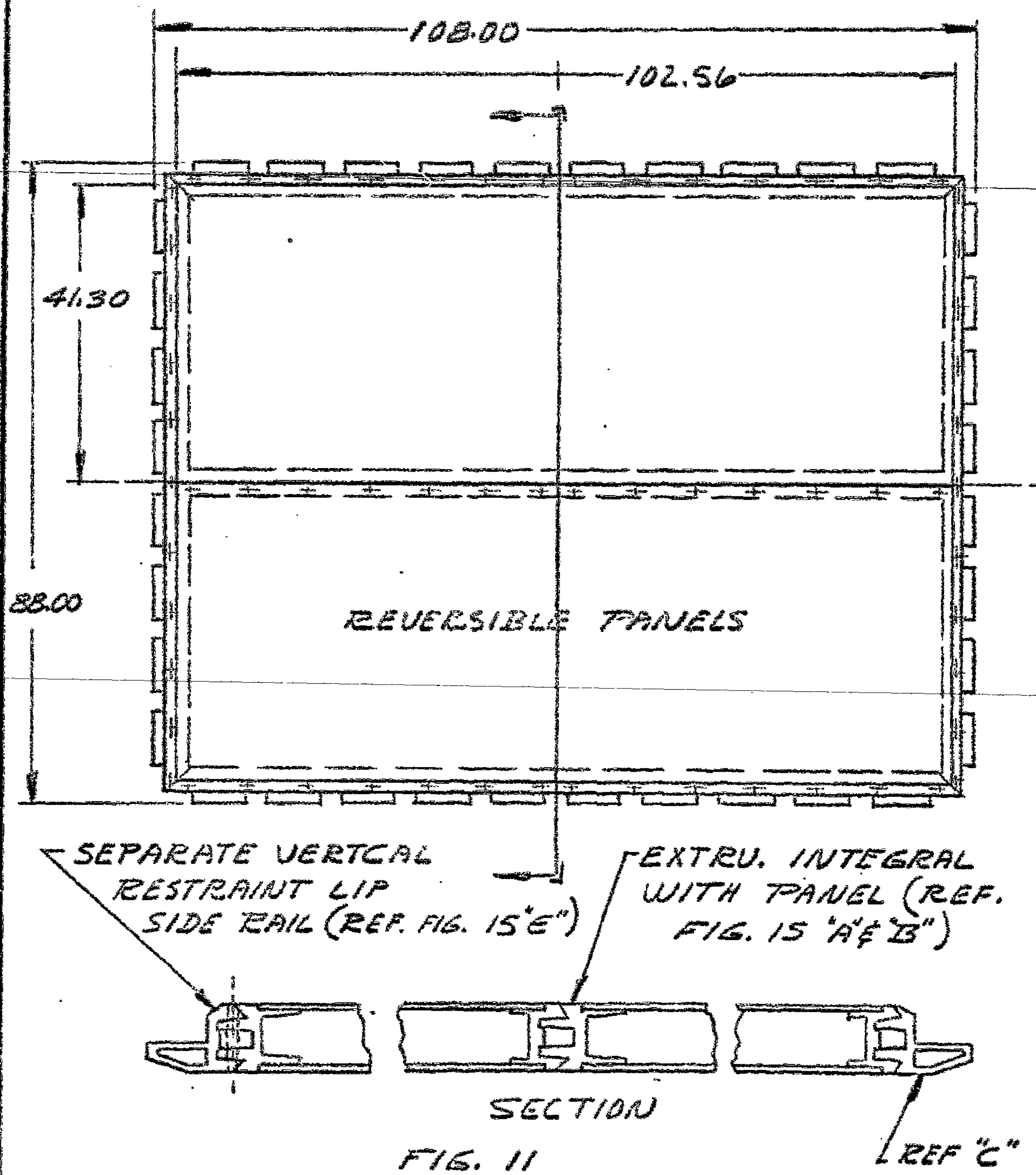


FIG. 11



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LOGISTICS PALLET - ONE 88" x 108" MODULE

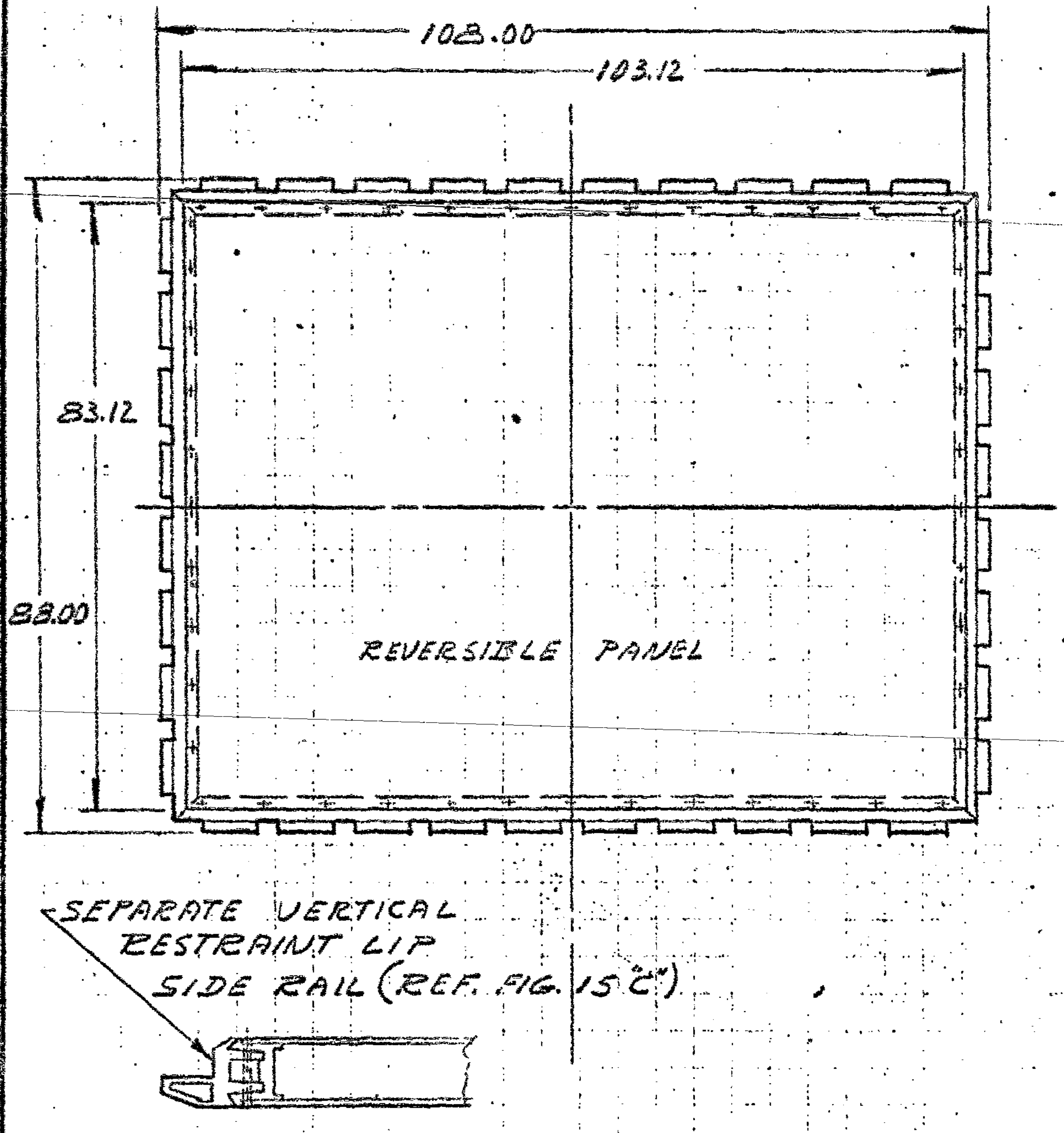


FIG. 12



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LOGISTICS PALLETS - ONE 88" x 108" MODULE

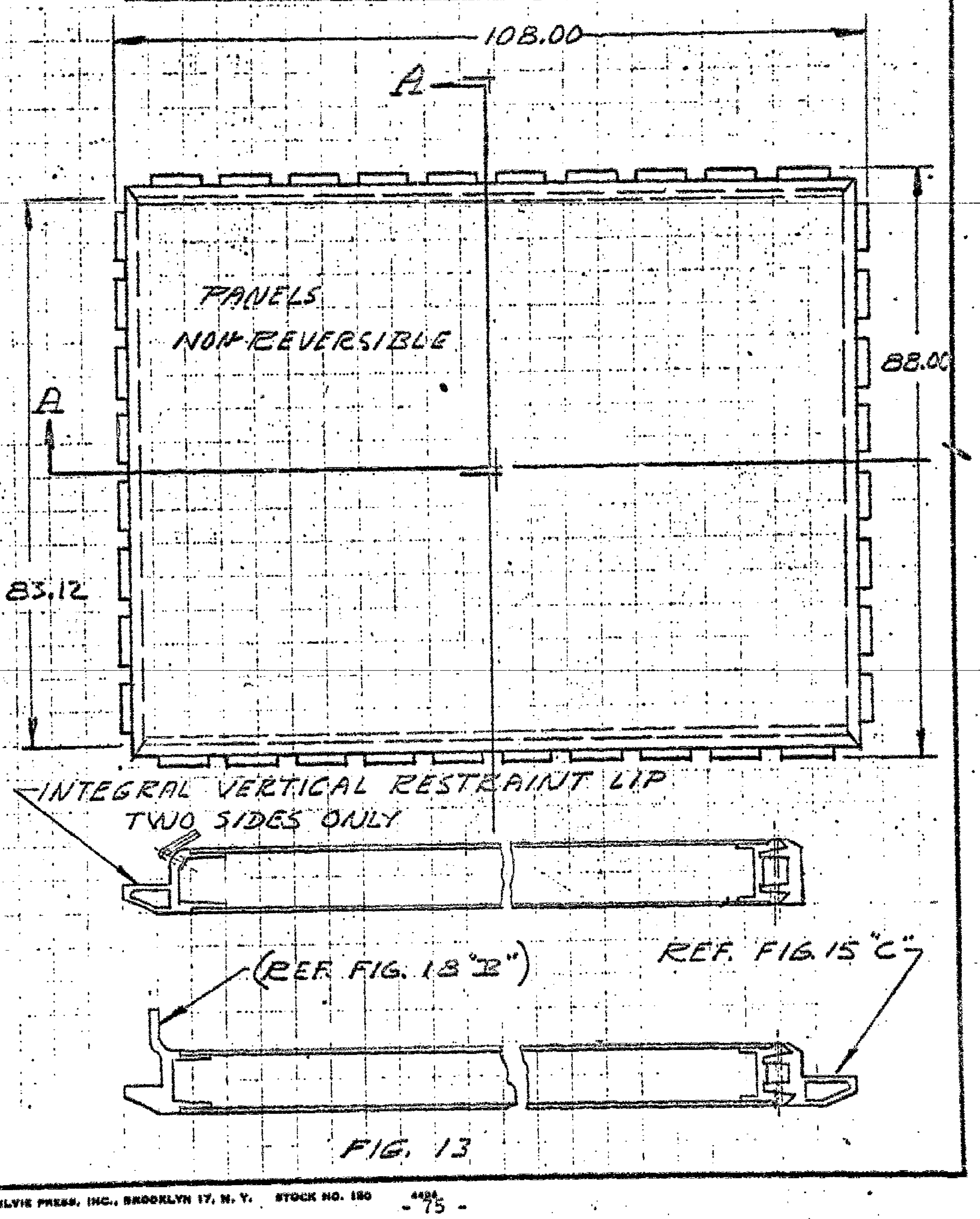


FIG. 13

TECHNICAL ANALYSIS FORM

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AIR-DROP PLATFORM MADE UP USING ONE SIZE MODULE
NOMINALLY 44" x 108"

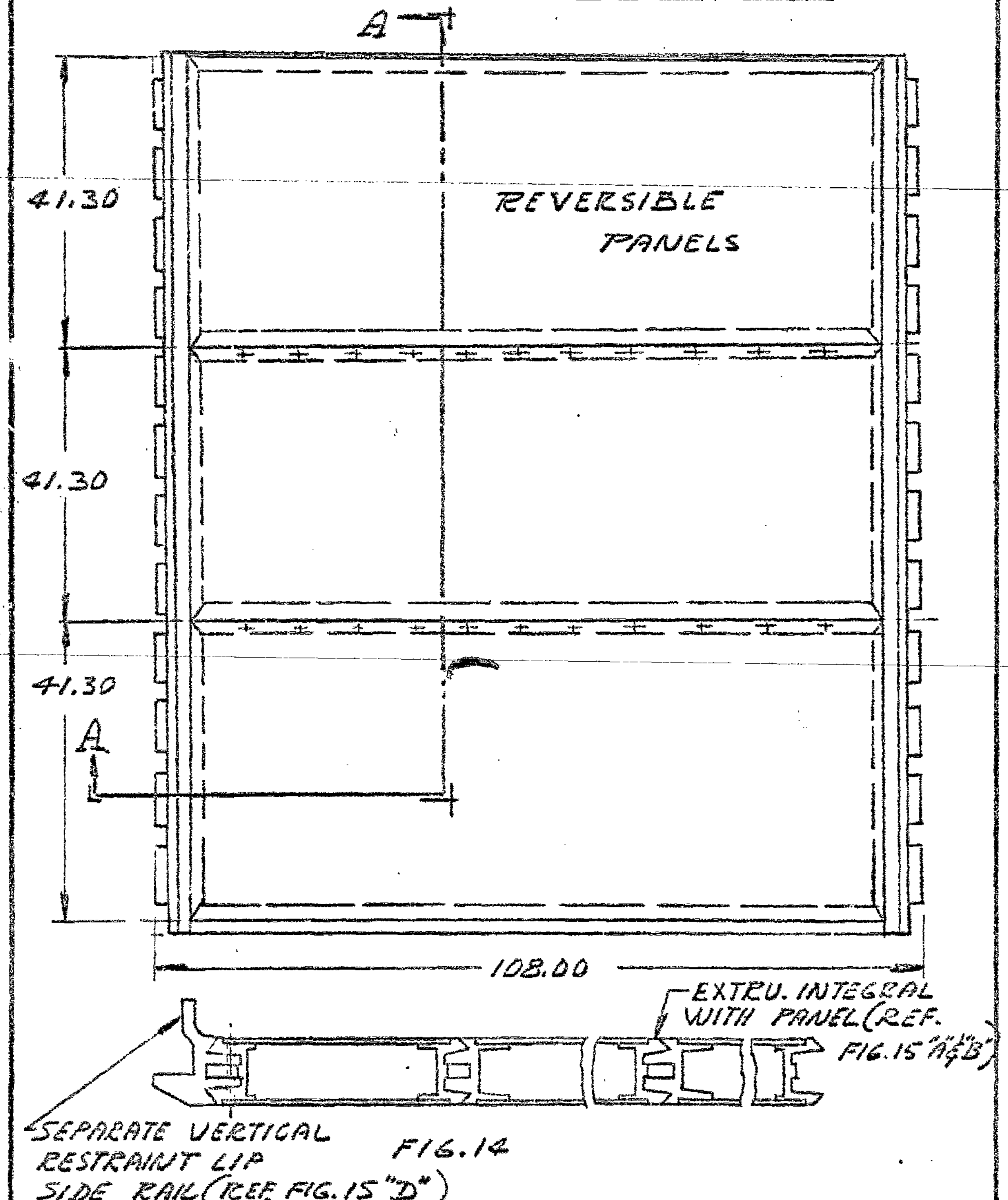


FIG. 14

TECHNICAL ANALYSIS FORM

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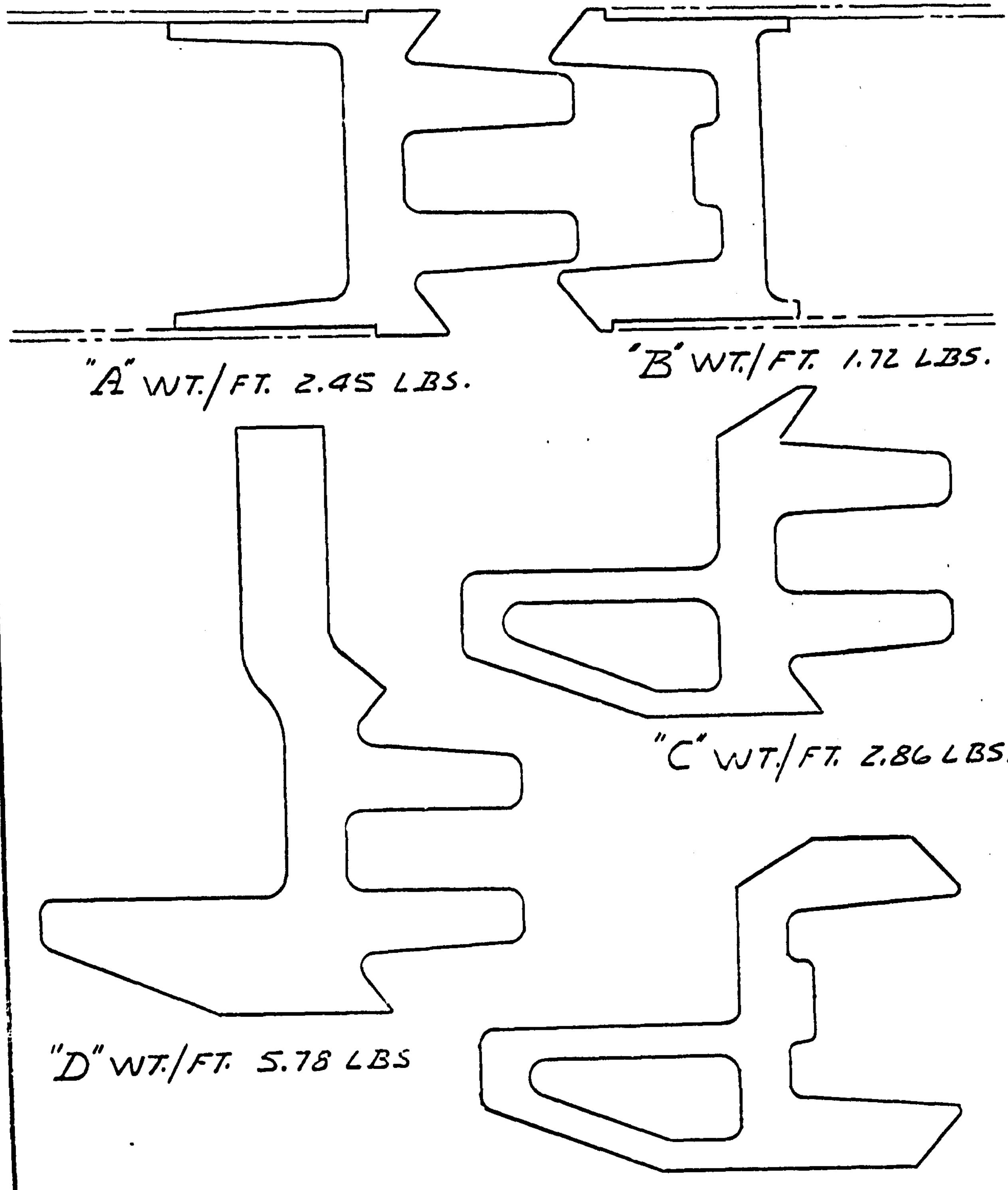
TYPICAL EXTRUSION SECTIONS FOR PANEL JOINTS
AND VERTICAL RESTRAINT LIP SIDE RAIL MEMBERS




"E" WT./FT. 2.69 LBS

FIG. 15



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## SECTION VIII

## CAPABILITIES AND LIMITATIONS OF THE SINGLE SIZED UNIVERSAL MODULE

The 44" x 108" module, when assembled with appropriate edging and joint members into a full size 88" x 108" pallet, would comply with the stated objective of ASNLM Exhibit 63-6. Although the pallet weight (385 lbs. vs. 290 lbs.) and cost ($309 vs $250) would be greater than the current 6/E pallet, the 44" x 108" module would:

a. Be the lowest production cost item consistant with the designed test requirements of the Statement of Work.

b. Be resistant to deterioration when exposed to world-wide climatic conditions.

c. Be easy to assemble in the field because of a minimum number of parts and ability to be assembled with simple hand tools.

d. Have structural continuity to enhance its reuseability.

e. Be capable of transporting general cargo and air-drop platforms.

f. Be compatible with existing 463L ground and aircraft equipment.

g. Be resistant to in-service operational handling.

h. Be capable of withstanding 9'Gs forward loading of 10,000" on an 88" x 108" logistics pallet.

i. Have top-to-bottom reversability.

j. Be one size only.

k. Have no unrecognizable orientation features.

l. Be assembled into a full size 88 x 108-inch logistics pallet.

m. Be assembled into 108" wide airdrop platforms greater than 28' long.

n. Is only 2 1/4 inches thick.

o. Meets the performance criteria specified in paragraph 4.4 of the Exhibit 63-6.

p. Uses currently produced materials fabricated by standard production processes.

However, the module is not truly a universal module for military air cargo. The 88" x 54" pallets used for TAC mobility supplies and LOGAIR cannot be assembled from the module. The only reasonable size providing true universality is the 44" x 54" size, rejected for inherently poor strength, high weight, high cost, and design complexity.

Furthermore, no improvement in the compatibility of platforms with the entire logistic system is expected. The 108" x 44" module size cannot be carried by the preponderance of wheeled vehicles that may be available in drop zones.

The estimated weight and the production costs of this Universal Platform module reveals the weight and cost increase that results when a single module is developed to fulfill both the logistics and air-drop missions.

| | WEIGHT | COST |
|---|---|---|
| Present 88" x 108" Pallet | 290# | $250 |
| 2- 44" x 108" modules joined to make 1 - 88" x 108" Pallet | 375# | $307 |
| Present modular airdrop platform - 12 ' long (3 modules) | 519# | $365 |
| 3 - 44" x 108" modules joined into platform 10' long | 568# | $424 |

For more detailed cost and weight information on other module sizes and airdrop platform lengths, see Appendix VII.

A preliminary cost/effectiveness comparison of the Universal Platform concept and currently used logistics and modular air-drop platform system reveals the primary disadvantage of the single-sized module concept. Although the cost of the Universal Platform modules would be much greater than the currently used platform, the performance of the assembled logistics and/or air-drop platform would be substantiately equivalent to items now in service. The advantage of processing a single size module would not compensate for the increased production costs of the item.

An objective review of the contract requirements and the data obtained during the field survey indicates that the total cost of the cargo carrying pallets may be reduced if the contractor deviated slightly from the definitive Work Statement, to allow two module sizes. Advantages of eliminating the one-module requirement are discussed in the following section.

# SECTION IX

## CAPABILITIES AND LIMITATIONS OF THE TWO SIZE MODULE UNIVERSAL PLATFORM SYSTEM

Two size module systems for air-drop platforms are shown in Figure 15 and 16. They consist basically of an 88" x 108" module plus add-on modules of 48" x 108" with separate side rails or 50" x 108" module with integral side rail members.

The air-drop platform system as shown in Figure 15 consists of:

1. A large module 88" x 108".
2. One or more smaller modules 48" x 108".
3. Side rail extrusion in lengths of 7, 11, 15, 19, 23 and 27 ft. according to length of platform.
4. A supply of spring pins.

The 88" x 108" module is the same as that shown in Figure 12. It consists of sandwich panel with a female type extrusion section edge member on all four sides. The 48" x 108" module has the same female extrusion on the two sides and one edge. The other edge member is a male extrusion section. To assemble a platform the small module is inserted into the edge member on the large module. Spring type retainer pins are used to secure the connections. Separate side rail extrusions must be used to obtain the vertical restraint capability. Platform lengths of 7, 11, 15, 19, 23 and 27 ft. may be obtained in this manner.

Figure 16 shows an alternate system in which the side extrusion members with the restraint lip are integral with the panel construction. The platforms are made up in the same manner as described above, with the exception that the side rails do not have to be added. The advantages of this system over the previous system is that with the side rails integral no additional rails have to be stocked and field assembly is made considerably easier.

This two size module concept does not comply with the stated objectives of a one size module of the statement of work, however, it does allow more universality in that the large module (88" x 108") is used for both the logistics pallet and the air-drop platform. As shown in Appendix I the basic 88" x 108" module will take care of approximately one third of all the Army equipment loading requirements as opposed to approximately 50% for the present 8 ft. air-drop platform. The cost and weight comparison is:

| | COST | WEIGHT |
|---|---|---|
| 88" x 108" air-drop platform Separate Side Rails | 284 | 368 |
| 88" x 108" air-drop platform Integral Side Rails | 271 | 344 |
| Present 8 Ft. Modular air-drop platform | 244 | 346 |

The two size module platform system:

a. Is the lowest cost system that incorporates some universality.

b. Is the most feasible from the standpoint of providing a universal platform system.

c. Will meet all the loading requirements for logistics and air-drop missions.

d. Incorporates a reversible panel design, with the separate side rails.

e. Provides the most structural continuity.

f. Is easy to assemble in the field because of a minimum number of parts and ability to be assembled with simple hand tools.

g. Is capable of withstanding the 9'G forward loading requirement for the 88" x 108" logistics pallet.

h. Uses currently produced materials fabricated by standard production processes. These materials are resistant to deterioration when exposed to world-wide climatic conditions.

i. Meets the performance criteria specified in paragraph 4.4 of the Exhibit 63-6.

j. Is compatible with existing 463L ground and aircraft equipment.

However, the module is not truly a universal module for military air cargo. The 88" x 54" pallets used for TAC mobility supplies and LOGAIR cannot be assembled from this system.

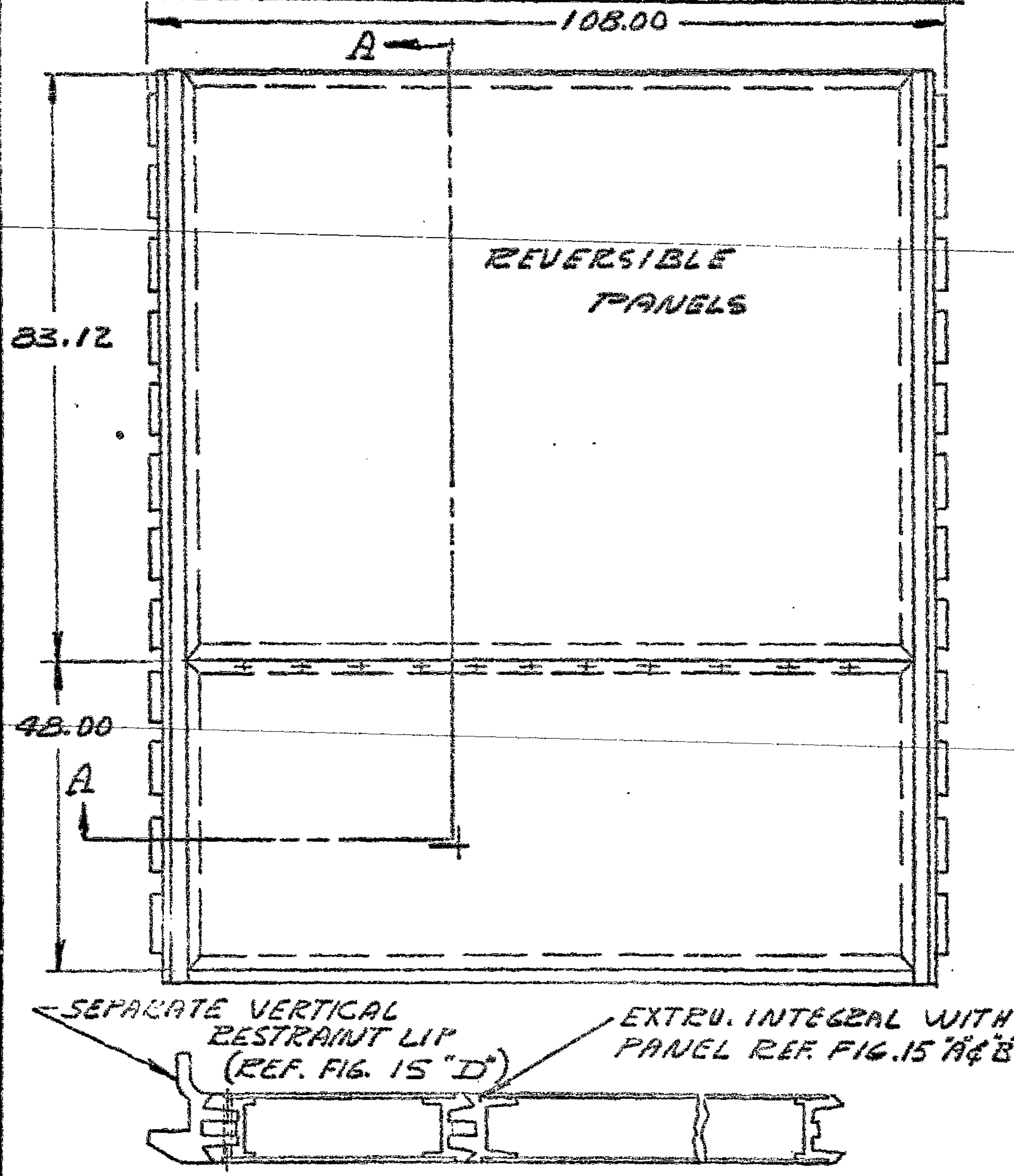
Furthermore, no improvement in the compatibility of platforms with the entire logistics system is expected.

The estimated weight and the production costs of this Universal Platform module reveals the weight and cost increase that results when a single module is developed to fulfill both the logistics and air-drop missions.

TECHNICAL ANALYSIS FORM

| BY H.R. GEIST DATE | BROOKS & PERKINS | SHEET ____ OF ____ |
|---|---|---|
| CK. ____ DATE ____ | B&P | SUBJECT ____ |
| REV. ____ DATE ____ | DEFENSE PRODUCTS DIVISION | |

AIR-DROP PLATFORM 88" x 108" MODULE + 48" x 108" ADD ON MODULES SEPARATE SIDE RAIL MEMBERS




SECTION A-A

FIG. 16

TECHNICAL ANALYSIS FORM

| BY H.R. GRISTI DATE 6-23-65 | BROOKS & PERKINS | SHEET ____ OF ____ |
|---|---|---|
| CK. ____ DATE ____ | b+p | SUBJECT ____ |
| REV. ____ DATE ____ | DEFENSE PRODUCTS DIVISION | |

AIR-DROP PLATFORM 88" x 108" MODULE + 50" x 108" ADD ON MODULES - INTEGRAL SIDE RAIL MEMBERS

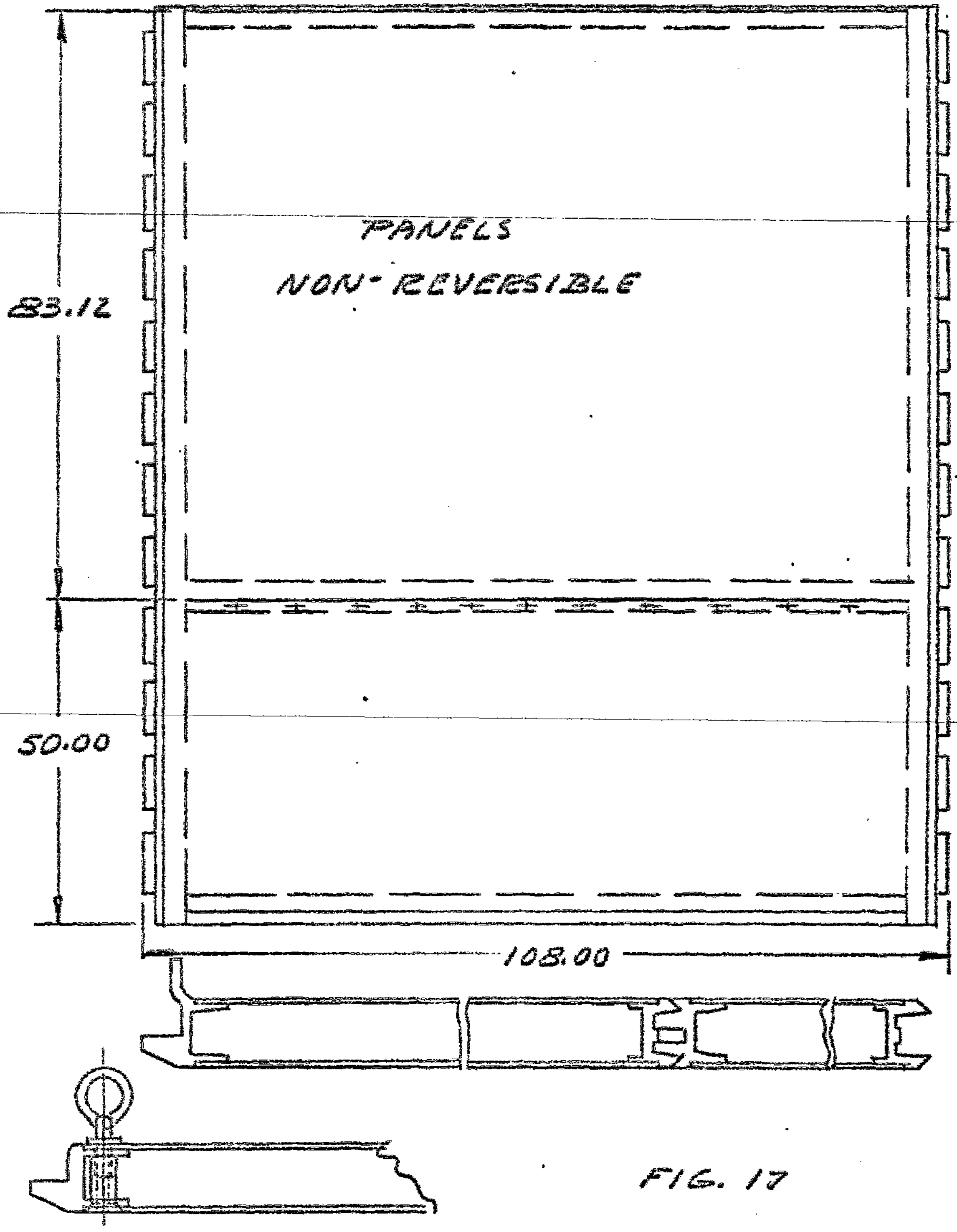



FIG. 17

TECHNICAL ANALYSIS FORM

| BY H.R.GEIST DATE 6-23-65 | BROOKS & PERKINS | SHEET ____ OF ____ |
|---|---|---|
| CK. ______ DATE ______ | b+p | SUBJECT ______ |
| REV. ______ DATE ______ | DEFENSE PRODUCTS DIVISION | |

OPTIONAL INTEGRAL VERTICAL RESTRAINT LIP SIDE MEMBERS WITH AIR-DROP TYPE TIE DOWN RINGS

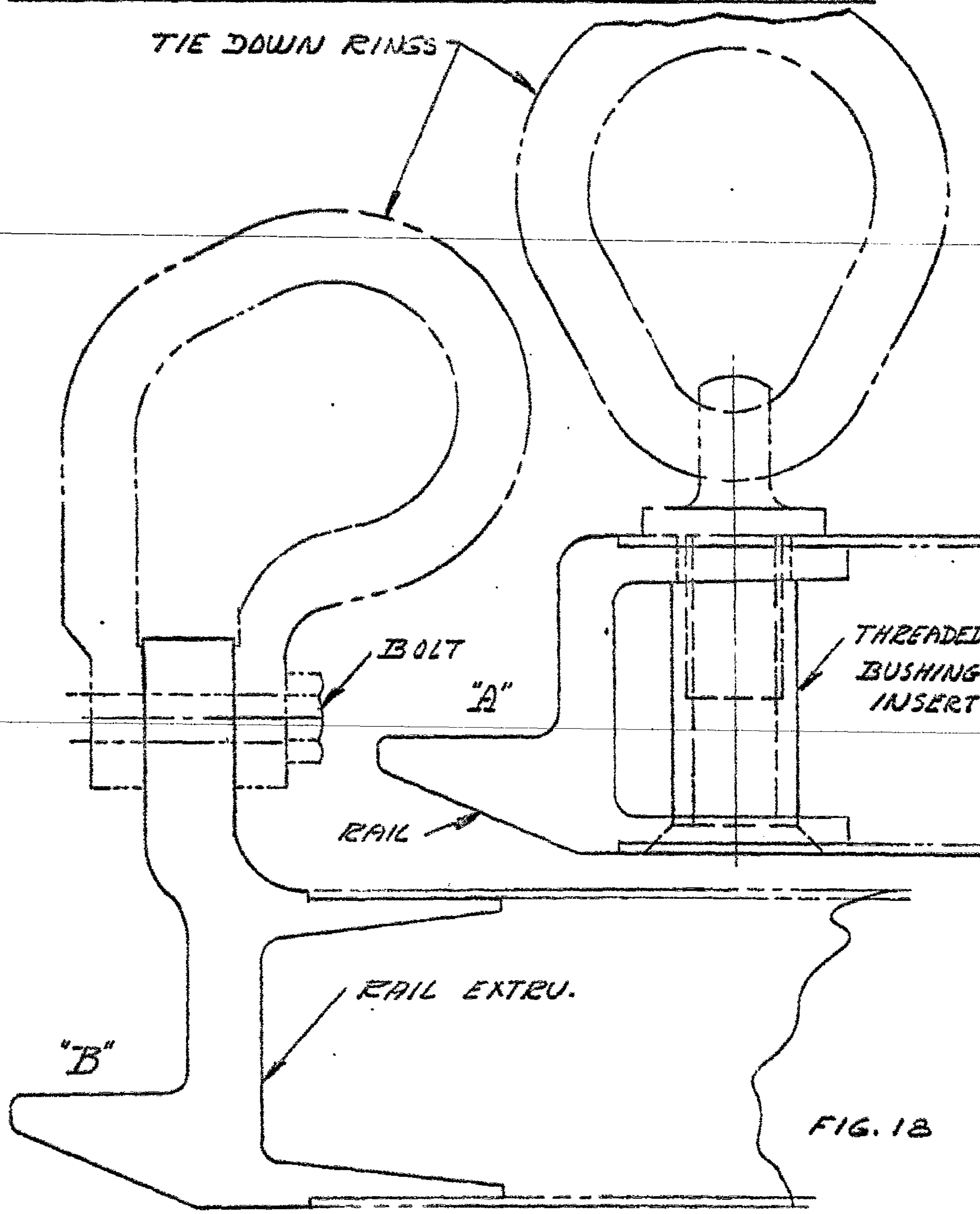



FIG. 18



OGILVIE PRESS, INC., BROOKLYN 17, N. Y. STOCK NO. 180 4400

TECHNICAL ANALYSIS FORM

| | | |
|---|---|---|
| BY [illegible] DATE 6-24-65 | BROOKS & PERKINS | SHEET ____ OF ____ |
| CK. ________ DATE ________ | b+p | SUBJECT ________ |
| REV. ________ DATE ________ | DEFENSE PRODUCTS DIVISION | |

OPTIONAL ADD ON BAR TO TAKE AIR-DROP TYPE TIE DOWN RING

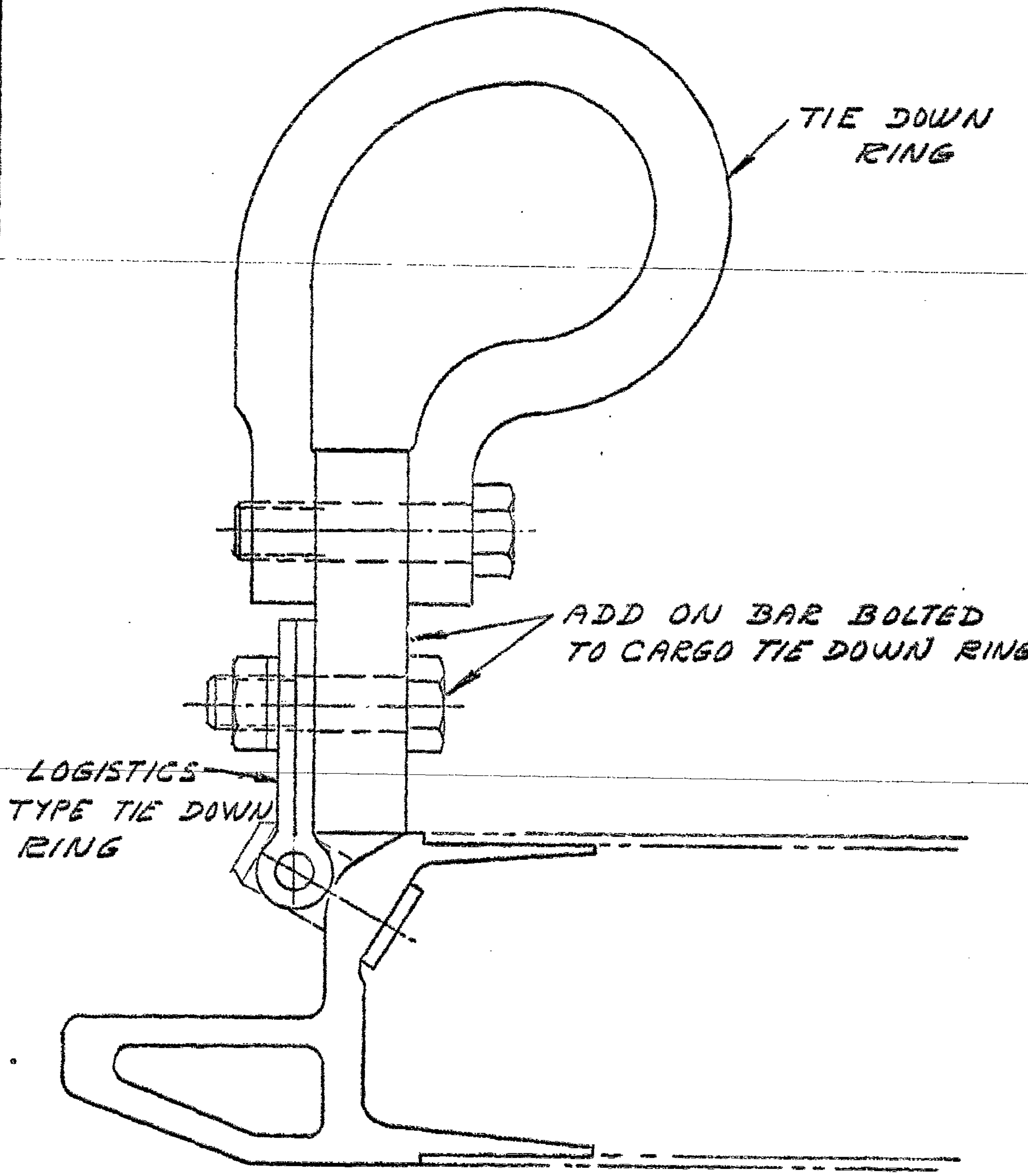



FIG. 18 A

# SECTION X

## CHARACTERISTICS OF THE RECOMMENDED PLATFORM

Paragraph 3a of the Statement of Work, ASNLM Exhibit 63-6 states in part "The contractor shall conduct an engineering study - - - - - to ascertain an optimum design of universal platform (s) - - - - -."

An optimum design is generally recognized to mean the achievement of maximum performance with a minimum of expense. The one-sized module, 44" x 108" described in Section XIII complies with nearly all the specifically defined requirements of the Statement of Work, but the performance of the assembled platforms would not be significantly greater than the currently used platforms. As a matter of fact, the consolidation of the logistics and air-drop platform into one "universal" platform would probably have a determental effect on the platform performance.

Throughout the study, the conflicting design requirements of the logistics and the airdrop platforms were compromised to develop the universal platform. After formulation of the 44" x 108" module, study efforts were redirected toward achieving an improved logistics platform and an improved air-drop platform.

LOGISTICS PALLET

What features should the logistics pallet have?

Information obtained during the field survey if user requirements reveal the predominent use of the full size, 88" x 108-inch pallet. There is very little need for the half size, 54" x 88" pallet. Although there may be a limited need for the smaller size, the design of an optimum logistics pallet should be based on the 88" x 108" standard.

The field survey also indicated that the present 463L pallets have a useful life of about 100 trips - and each trip averages 6000 miles. Primary calculations of the air freight cost of transporting the current 88" x 108" 463L pallet averages 39 dollars per trip! This cost is almost twenty (20) times greater than the amortized production cost of the pallet. See appendix III for more detailed discussion of the transportation costs.

A light weight logistics pallet should be developed to reduce these excessive transportation cost. A fifty pound weight reduction in the 463L pallet would provide savings of approximately four hundred thousand dollars per year.[1]

Initial studies of production and transportation costs, weight, and pallet life expectancy indicates that the optimum logistics pallet would be light weight, marginal strength, and limited useful life. Determination of this optimum design, however, is beyond the scope of current Statement of Work. (About seven (7) pounds would be removed from the 463L pallet weight if the thickness of the pallet could be increased from 2 1/4 x 2 3/4-inches.) The potential cost savings which would be derived from the results of such a study would amount to several million dollars.

The logistics pallet should -

a. Be 88" x 108" panel (one size only.)

b. Be of minimum weight.

c. Comply with all other requirements specified in the Statement of Work, ASNLM Exhibit 63-6.

The logistics pallet described elsewhere in this section has been designed to incorporate these features.

---

[1] 57000 pallet - trips per year x 50 pound weight savings per pallet x 0.1345 dollars per pound per trip = 385,000 dollars.

AIR-DROP PLATFORM

What features should the air-drop platform have?

From the field survey it was determined -

1. Platform width should be 108".
2. ~~Modular panel concept has been satisfactory.~~
3. The number of different parts to be carried in inventory, and excessive disassembly time are two deficiencies of the current modular platform system.
4. Currently used platforms do not have sufficient reuseability.
5. Platform damage occurs at the "stress riser" locations of the modular assembly.
6. LAPES imposes a wide range of random loading conditions on the air-drop platform during ground impact.

The addition of the low.level air delivery capabilities to the contractural performance requirements of the air-drop platform has accentuated the fundamental differences of the logistics and air-drop platform.

Establishment of an optimum weight, cost, reuseability parameter for the design of the air-drop platform defies solution because of the near uncontrollable conditions at ground impact. A review of slow motion film coverage of LAPES operations and a study of APGC-TR-64-61 report, "Evaluation of C-130 Aircraft low altitude parachute extraction system "prepared by APGC, Eglin AFB, shows the critical relationship between the loaded platform CG. and the direction of the extraction force. Excerpts of APGC-TR-64-61 are presented in appendix

The recommended air-drop platform should -

a. Maximize the utilization of aircraft cargo space.

b. Have restraint lip integral with the module.

c. Have interlocking lateral edges of the module so that the joint will have stiffness and strength characteristics approximately equivalent to the basic module.

d. Should be easily repairable.

e. Should have a minimum of different inventory items.

f. Should provide for cargo tie-downs on all four edges of the assembled platform.

g. Should be so designed that the probable stress level of the structural elements of the module will not exceed the proportional limit of the material.

h. Comply with all other non-conflicting requirements of ASNLM Exhibit 63-6.

The air-drop platform module and assembly described elsewhere in this section has been designed to incorporate all of these features.

Deviation from the one-module limitation provides the military with a substantially lower cost logistics pallet and with an air-drop platform having increased reuseability.

LOGISTICS PALLET DESCRIPTION

Figure 19 illustrates the logistics pallet recommended to comply to the objectives of the Statement of Work. A casual glance of the drawing indicates similarity with the HCU-6/E pallet now in production. Differences occur however in core material, skin thickness and alloy, number of tie-down rings and corner construction. The calculated weight of 240 pounds is substantially lower than the 290 pound weight of the present 6/E pallet.

The core material is resin-impregnated paper honeycomb weighing approximately four pounds per cubic foot. Final specification of density, paper weight, cell size, and degree of impregnation will be established following additional laboratory testing of core-facing combinations.

The facing material is .063 7075-T6. Stress analysis of the 2 1/4 thick pallet, subjected to a 90,000 pound forward loading condition, requires minimum of this much material. Laboratory tests of .063 7075-T6 skins bonded to appropriate density of resin-impregnated paper honeycomb, will successfully pass the 750 psi puncture test requirement.

The restraint lip of the peripherial edge members is shaped to be more resistant to in-service operation and handling. 6061-T6 aluminum alloy has been selected because of its good cost, strength, and extrudability properties. Indentations at 10-inch spacing conform to the 463L System requirements.

Improved structural continuity of the corners of the pallet is obtained by incorporation of an "L" shaped splice bracket shown in Figure 19. This bracket is designed to minimize one of the primary causes of pallet damage and scrapage - i.e. breakage at the mitered joint of the adjacent edge members.

Standard epoxy resins and anti-peel rivets join the structural components into an integral 88" x 108" logistics panel.

Six 10,000# capacity tie-down rings are installed along each of the four edges. The rings at the corners are expected to be loaded to near capacity during the 9 G test condition.

The other rings will be subjected to loads of only 6,000#, 4,000# or even less. For replacement purposes, however, and to avoid the possibility of inadvert mis-located ring, it was decided to make all rings the full 10,000# capacity. Location of the rings was developed concurrent with the development of the 9 G, 10,000# capacity cargo restraint.

This pallet provides the following benefits:

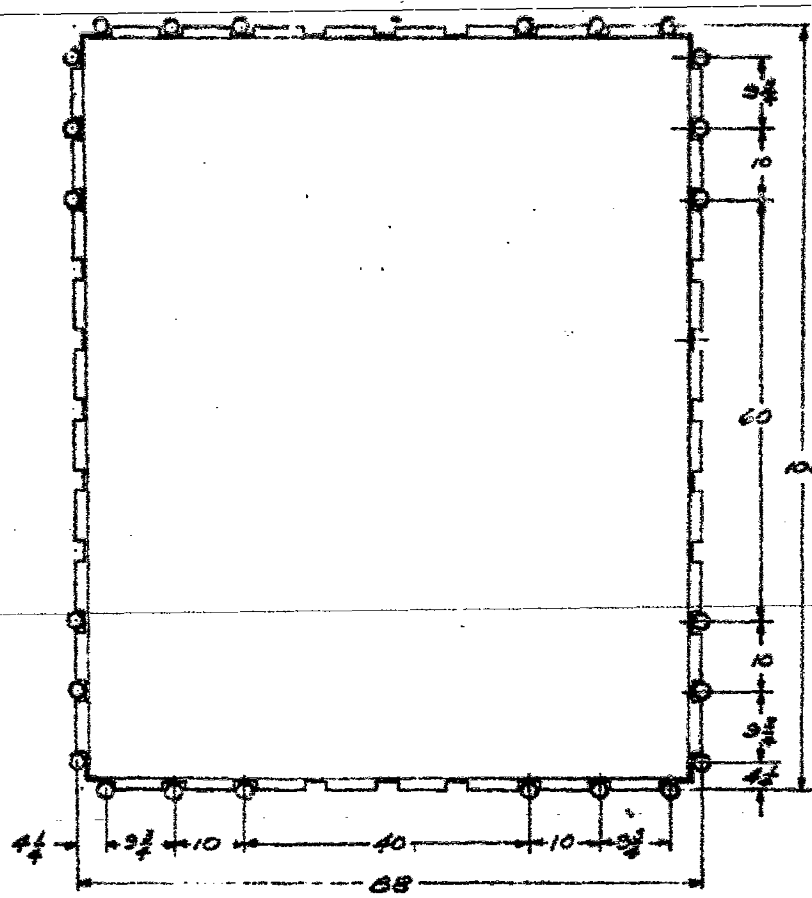
1. Improved edge members and the reinforced corner construction will reduce the pallet damage and replacement rate.

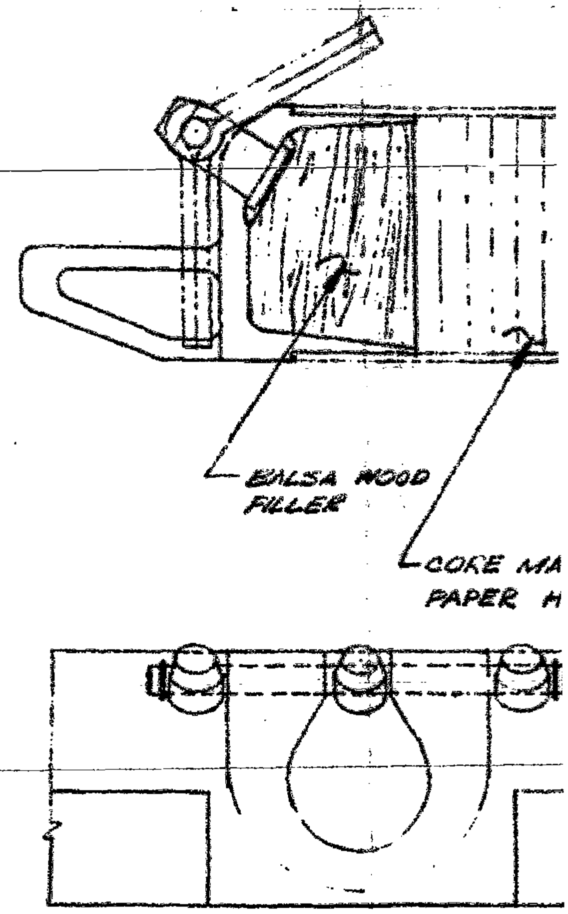
2. An improved cargo restraint and pallet interface provides a 9 G static forward loading capability not attainable in the 6/E pallets currently in service.

3. The reduced weight results in a potential transportation cost savings of several hundred thousands of dollars per year.

PROPOSED LOGISTICS UNIVERSAL PALLET

FIG. 19

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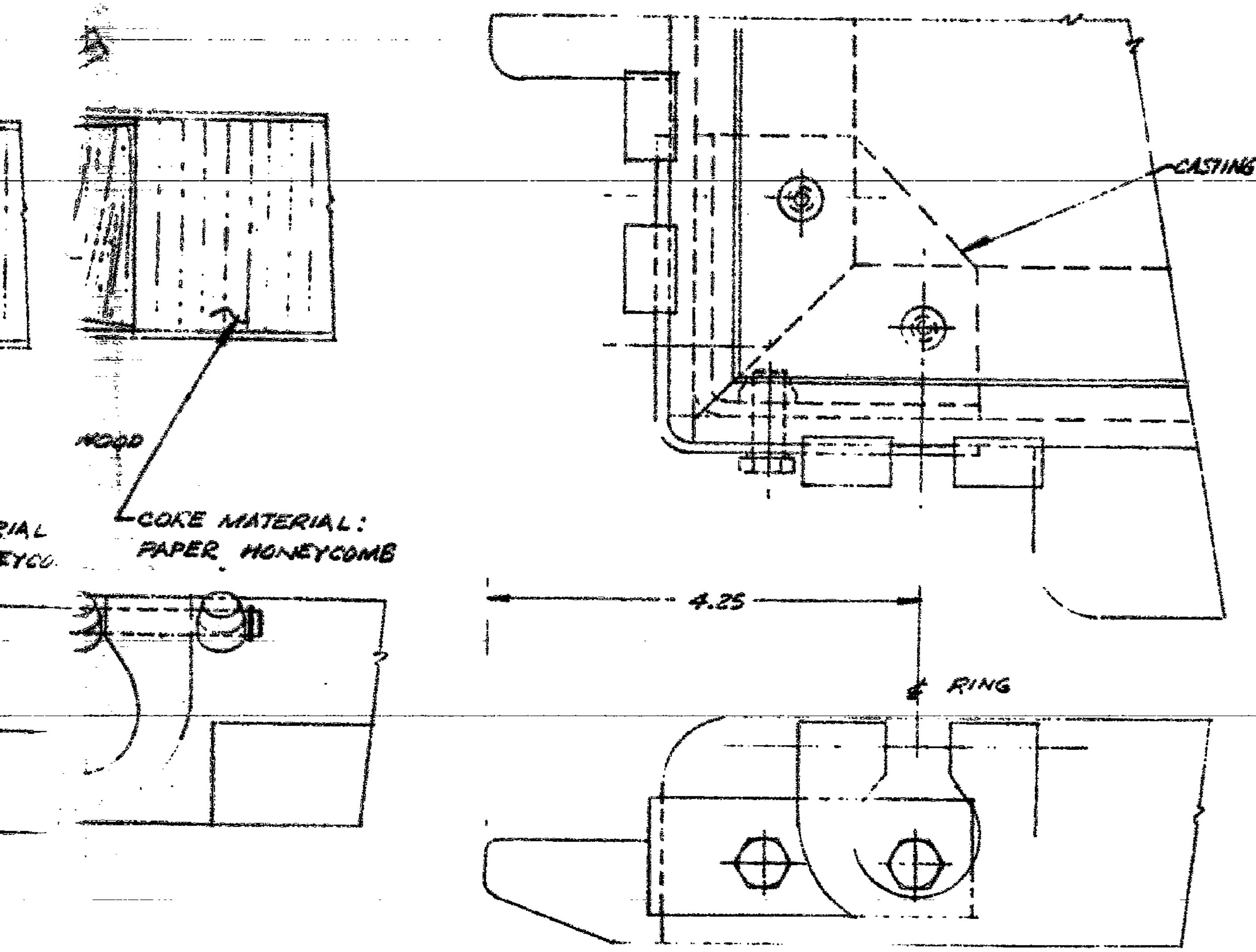
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B

# CARGO RESTRAINT DEVICE

ASNLM Exhibit 63-6 specifies the cargo restraint device shall:

1. Restrain miscellaneous cargo during ground handling and flight operations.

2. Be readily used by personnel with little training.

3. Be applied to the load with minimum preparation.

4. Have recognizable orientation features.

5. Be designed for manual application.

In addition, the preliminary stress analysis of the logistics pallet indicated that the distribution of the restraint forces must be directed toward the outboard edge of the pallet. A device with a uniform distribution of restraint would introduce prohibitive bending forces on the aft edge of the pallet during the 9 G forward static load condition.

## Material Selection

A wide range of metallic and non-metallic materials have been examined and evaluated for their attributes in a variety of basic characteristics. These characteristics are summarized below in their order of relative importance.

a. Strength Weight Ratio.

b. Degradation due to exposure to Ultra-violet light.

c. Resistance to Humidity.

d. Abrasion Resistance

e. Degradation due to exposure to heat.

f. Resistance to Corrosive Atmosphere.

g. Stiffness.

While not a condition of the Statement of Work, it was believed advisable to study the energy absorption characteristics of the various material selected. Comparative information on Nylon, Dacron and Steel have been compiled. This comparison showed Nylon to be superior to this regard. Proper consideration is given to this property.

The following materials were evaluated during the study -

1. Synthetic Fibers

| | |
|---|---|
| Rayon (Viscose) | Acetate |
| Polyurethane (lycra) | Nylon 6,6 |
| Polyester (Dacron) | Nylon 6 |
| Polyethylene | Acrylic |
| Polypropylene | (orlon) (Acrilan) (Creslan) |
| Modacrylic (Dynel) | Saran |
| Flurocarbon (Teflon) | Glass Fiber |

2. Natural Fibers

Cotton
Manila
Linen
Hemp

3. Metal Strand and Rod

Steel
No other metal was considered because of the economic factor.

Tension members are the most satisfactory means of load transfer through the restraint device into the platform.

The ability of the material to be fabricated into a tension member is also considered of prime importance.

Evaluation of all of these characteristics indicated that the following materials in the raw form noted were worthy of consideration for use in the restraint system.

| | | |
|---|---|---|
| Steel | - | Strand, Rod, Strap |
| Glass | - | Multifilament |
| Polyester | - | Multifilament |
| Nylon | - | Multifilament |

Of the foregoing, all of the materials could economically be produced in forms adaptable to known and proven manufacturing techniques. Steel can be utilized in the form of stranded cable or chain. Glass fiber, polyester and nylon are best utilized in the form of webbing or rope.

While all of these materials can be fabricated into tension members, another characteristic of prime consideration is the stiffness of the basic fibers or strands. Glass fiber has a stiffness so great that processing from single filament into multifilament yarn reduces the initial filament strength by one-half. Further processing produces continual reduction. In addition internal fiber abrasion caused by continual flexing while in use will significantly reduce the strength.

Introduction of gripping and attachment mechanisms to the finished member greatly impair the load carrying capability.

A recently developed material which shows potential promise as a restraint device material is filament stainless steel that migh conceivably be fabricated into rope or webbing. While this material can be produced in the raw filament, very little information regarding manufacturing techniques is available. Since the development of new manufacturing techniques for basic materials is beyond the scope of this project, no recommendation is made to incorporate this material into the restraint at this point. It is believed that further information regarding the adaptability of steel filament as a tension medium should, however, be pursued.

Combinations of material have also been considered as possibilities for tension members. Generally it can be said that when tensile strength is the primary strength requirement, the introduction of materials inferior to the basic material will reduce the overall strength weight ratio. In the case of glass fiber, where the strength of the basic fiber is so high, a combination which would correct the stiff ness objection seemed worthy of examination. Discussions with several web manufacturers indicated that a combination of glass fiber and teflon or polypropylene could be produced, but the cost would be relatively high. It was also doubtful that a combination would overcome the strength reductions occasioned by the application of gripping and attachment mechanisms, since the only way of transferring load is directly from the gripping mechanism into the glass fiber.

When considering webbing as the tension member, it must be remembered that the fibers which carry the load are oriented generally parallel to the web length. A close balance must be maintained between the cross fibers and the longitudinal fibers, and in some circumstances greater tensile strength can be obtained by addition of cross fibers (filler) of different material than the basic fiber. A case in point would be the addition of nylon as a filler to certain cotton webbings. This is not, however, true in the case of addition of cotton filler to nylon webbing.

Combinations were also considered for shielding Nylon and Dacron from ultra-violet light. An exterior cover of cotton would materially reduce degradation due to ultra-violet. When different fibers are used as a cover, elongation ratings of the fibers of the cover materials and the structural material must be similar. This qualification is not true in the case of Cotton and Nylon or Dacron, and the Cotton cover would separate long before the Nylon or Dacron reached its ultimate capacity. This is also true of Polypropylene and Creslan. Teflon has desirable elongation and light resistant characteristics, however, it would not be economically feasible because of the high cost of raw material.

It should be noted that additional thickness of Nylon and Dacron can also provide protection to the inner fibers as shown by the comparison of exposure of yarn and exposure of webbing in sunlight.

If a period of one year continual exposure were selected as the criteria for light resistance, then approximately thirty percent more Nylon would be needed to provide desired capacity at the end of the period. Dacron would require an additional eight percent of material to provide desired capacity.

The additional cost of material to provide protection from ultra-violet light would be thirty percent for Nylon and eight percent for Dacron.

Having used Nylon as an index of 1.0 in cost evaluation, this additional consideration would indicate that a web device of Dacron would cost only 10 percent more than an equivalent Nylon device.

Steel compares favorably with both Nylon and Dacron in all areas except flexibility, strength weight ratio and the profile of the member contacting the cargo. Adjusting, releasing and tensioning devices are also cumbersome. For these reasons, steel is deleted from the list of possible materials.

There is little choice between Dacron and Nylon, if the energy absorption characteristics are discounted. Strength weight ratio is almost identical in the type webbing normally available.

There is little difference in the manufacturing and assembly procedures. The greater bulk necessary for retardation of light degradation in Nylon is offset by the higher cost of Dacron fiber. If additional material is added for prevention of light degradation, the fact that less is required to protect Dacron and Nylon will allow for a lighter device if manufactured of Dacron. For example 8,700 lb webbing in Dacron and Nylon weigh 7.8 and 7.7 pounds per hundred feet respectively. Since 30% additional Nylon and 8% additional Dacron is required for protection from ultra-violet light, the Nylon web portion of the device would weigh 1.19 times that of Dacron.

Past experience indicates that the web portion of a restraint device constitutes 43 percent of the total weight. A Nylon device including hardware would than be 1.09 times heavier than a Dacron counterpart.

In conclusion it would seem that there is little choice between Dacron and Nylon, however, on the premise that Dacron will be more resistant to light degradation and approximately 10 percent lighter than Nylon, it is recommended that the restraint device be fabricated of dacron webbing.

## 2. Detailed Design Considerations

The 9 g static load condition will impose extremely high loads on the restraint and pallet combination. Reactions at the pallet, due to restraint loads, are calculated to be twice as high as the reactions that occur during the 8 g deceleration for 0.1 second. Since a restriction has been imposed on pallet thickness, thereby limiting its bending strength, the attachment points for the restraint have of necessity been located close to the corners of the pallet.

Loads imposed by the restraint have been limited to specified maximum values. Restraint attachment fittings are located at points 4 inches, 14 inches and 24 inches inboard from each of the corners along each edge of the pallet. Loads are specified to be no more than 10,000 lbs. at the 4 inch location, 6,000 lbs. at the 14 inch location and 4,000 lbs. at the 24 inch location. Figure 21 indicates this orientation of webbing types. To accomplish this, webbing members, having similar elongation characteristics under the specified loads, were selected.

Further in this regard, the webbing locations on the load have been arranged so that the proper load segment is applied to each web.

A sketch of the proposed webbing locations is shown in Figure 22. It should be noted that since a single restraint module is proposed, the load will not always be distributed in proper ratio to each web. Since the short pallet side has higher bending strength, higher loading is shifted to the inboard webs in this condition.

A single module then poses the problem of adjustment to both long and short sides of the pallet. The necessary adjustment is accomplished by an arrangement of diagonal members, self adjusting to the 108 and 88 dimensions of the logistic pallet module. No adjustments other than height adjustment and corner draw webs are required.

An isometric of the proposed restraint is shown in Figure 23. It will be noted that two identical modules are utilized. One module covers the cargo front to rear and the other side to side. Members A, B and C are the load carrying members and are rated at 10,000 lbs., 6,000 lbs, and 4,000 lbs. respectively.

A series of diagonal members rated at 4,000 lbs. are added to this basic configuration to form a net pattern which eventually becomes the front, rear and sides of the cage.

This diagonal pattern is 48 inches high and has no vertical height adjustment.

Vertical web members attach at the apex of each two diagonals and runs across the load to the apex of similar diagonals on the opposite side of the load. Vertical web strengths are compatible with strengths of members A, B and C.

All adjustment for height of load occurs in these verticals. Just below the 96 inch level are located tensioning, adjusting and releasing devices which provide approximately 40 inches of adjustment. Twenty inches beyond are reefing hooks which allow for another 20 inches of retraction. This arrangement is duplicated on the opposite end of the module, providing a total of 120 inches of adjustment.

Figure 24 effectively shows dimensional characteristics of the module.

Two draw members are provided on each side of the module. Attachment hooks are provided in the draw members for attachment into similar draw members on the mating module.

Tightening the draw member effectively encloses the entire load.

Lateral webs are attached to the parallel cross members to space them and to provide them with load enclosing capability.

No single loose straps are utilized. This reduces the tendency to tangle.

A roll up bar is provided at each end of the module. This bar is provided to facilitate handling and storage and to prevent tangling. The bar is attached just above the attachment hooks and is expandable from the 88 inch to the 108 inch dimension.

The rod is fabricated of polyvinylchloride tubing of such durometer that it can provide the required torsional strength to roll up the module, yet withstand the abuses encountered in service. It will bend to load contour or can be run over by a fork lift truck without damage.

Hooks are utilized for attachment, basically because lifting requirements on the pallet dictated rings, so hooks seemed the simplest type of connection.

One of the basic problems with the hooks in previous nets was loss. A new type hook and keeper assembly is shown in Figure 25. The hook member is a three part stamping which when assembled prevents separation of hook and ring. The keeper arrangement is also unique in that it is almost completely protected by the hook member thereby minimizing the chance of damage or loss.

The hook is designed to minimize the possibility of hooking into the webbing and causing tangling and the hook opening is made only large enough for entry of the intended rings and attachments. This type is used throughout the restraint.

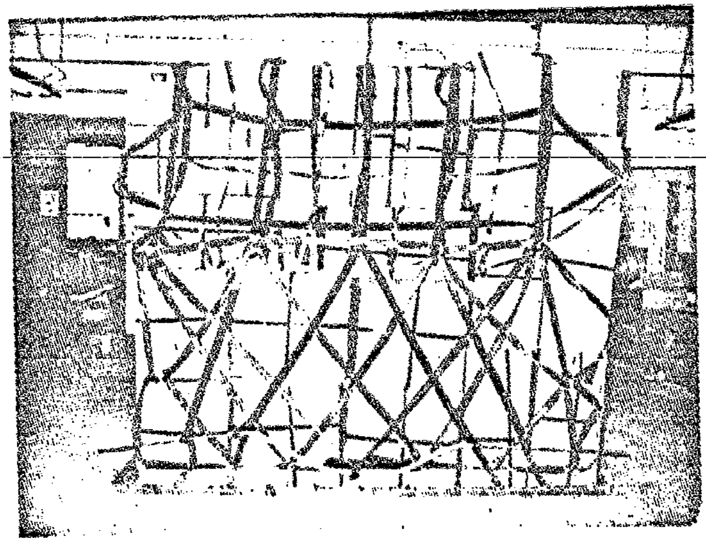
Figure 26 shows the detail of the adjusting tensioning and releasing device. It is a two bar double wrap type of web holding device. The web can be pulled thru the device hand tight and the device locked. Release is accomplished by release of a latch on the locking handle. Three bar parachute type hardware has been examined, but none will hold the large loads inherent in this restraint.

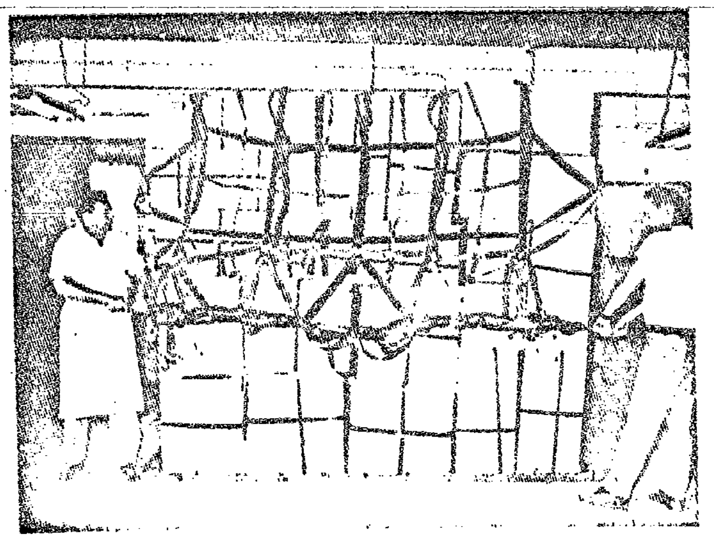
A reefing ring is provided on the top end of the device.

All tightening action is downward, which is proper from the human factors standpoint.

Photographs of a sample module are shown on the following page. (Figure 20).

A determination of loads in the structural members is shown in Appendix .





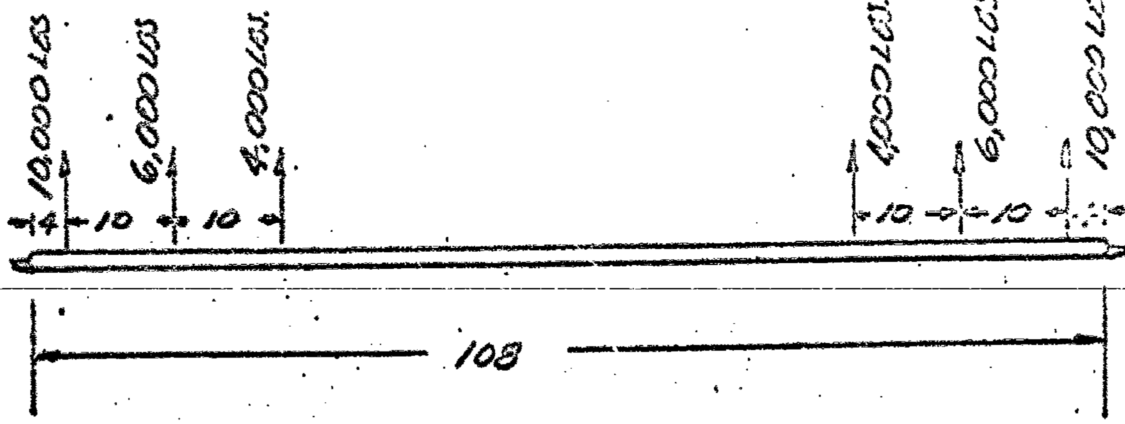



FIG. F-21

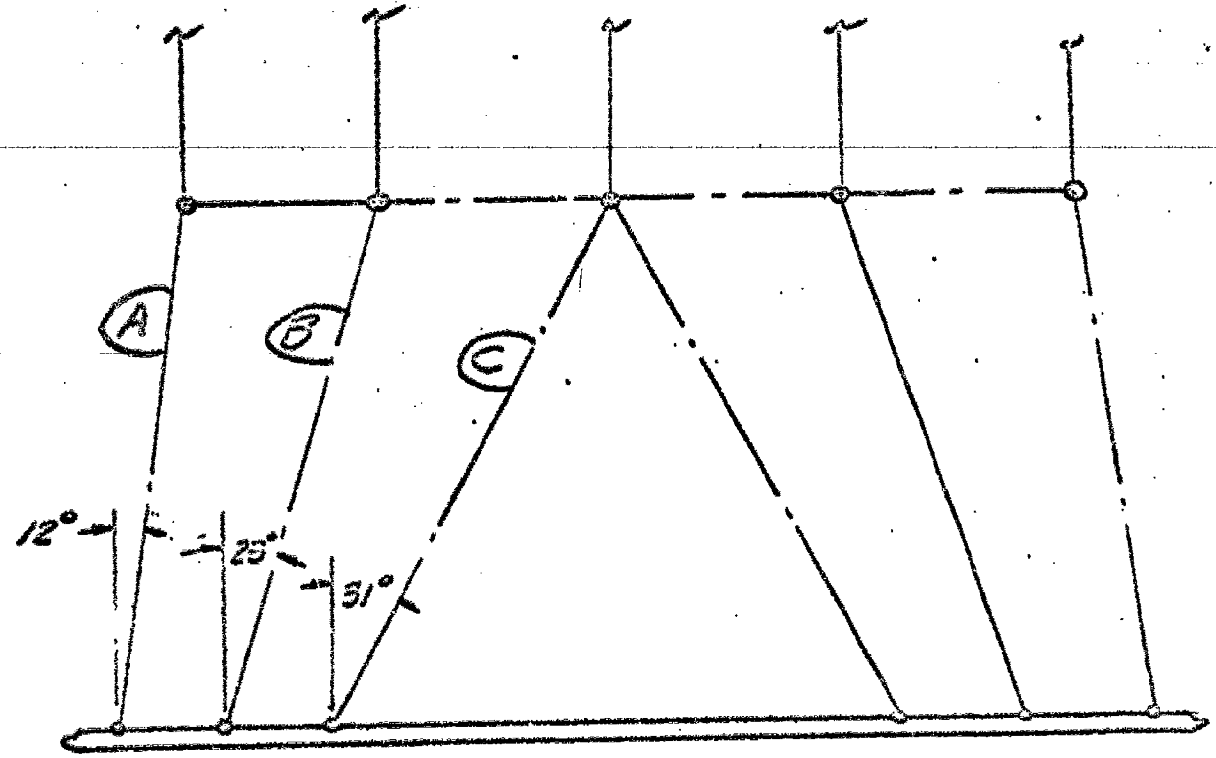





FIG. F-22

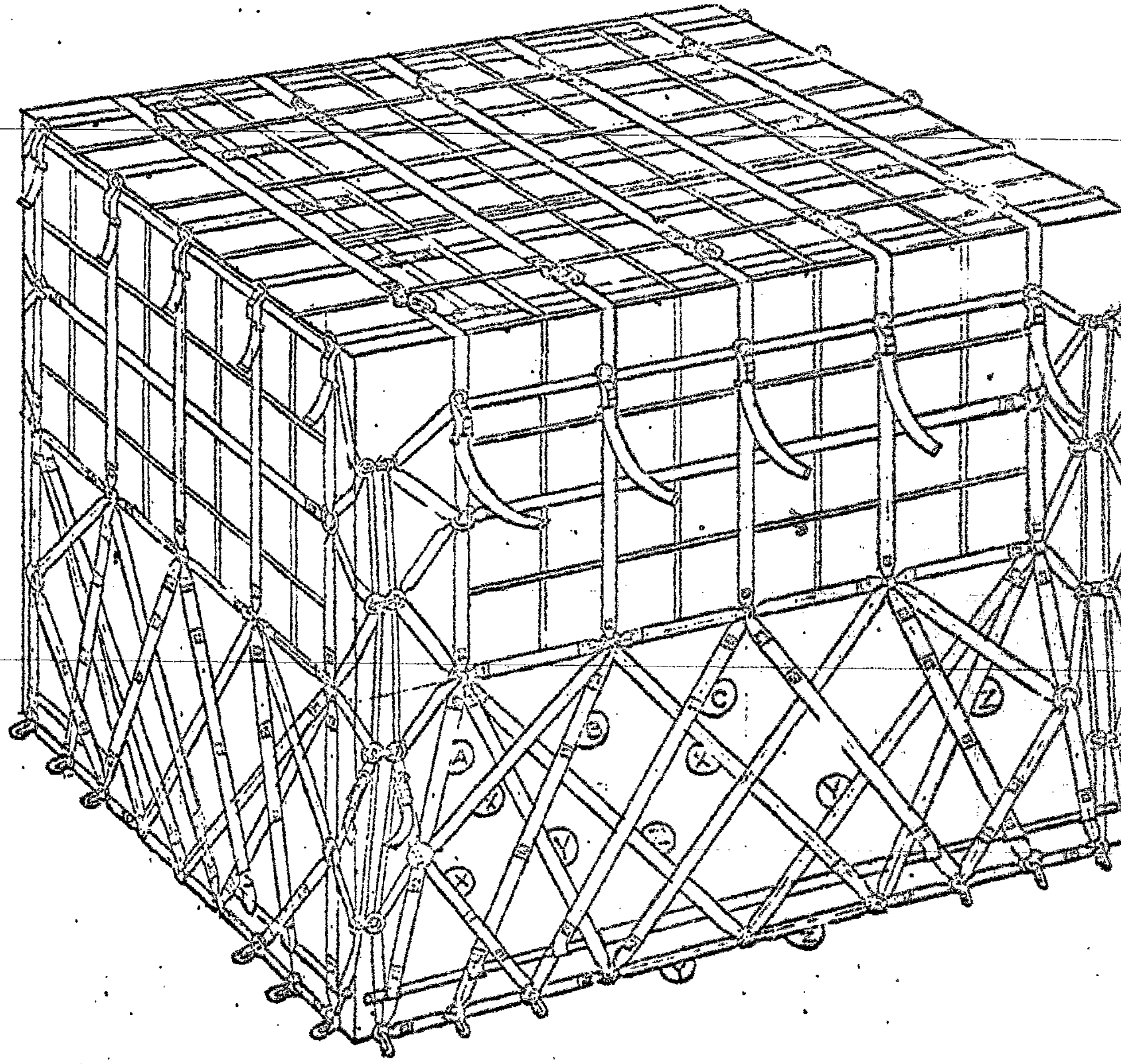




FIGURE F-23

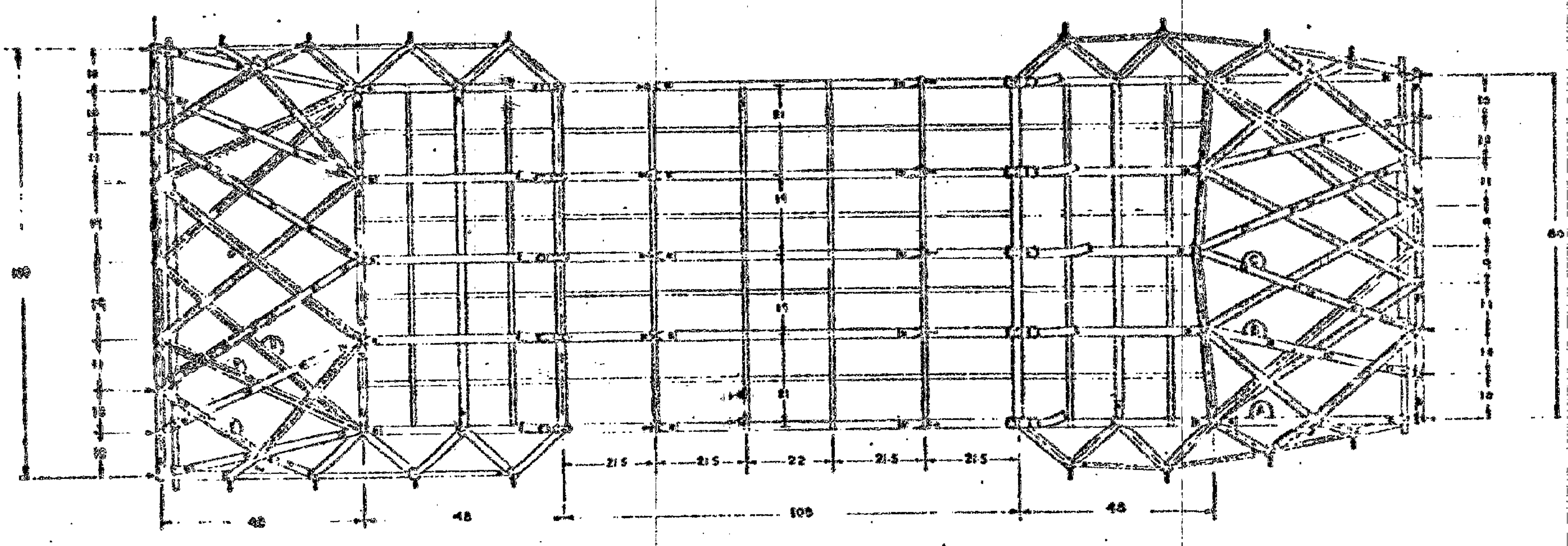



FIGURE F-24

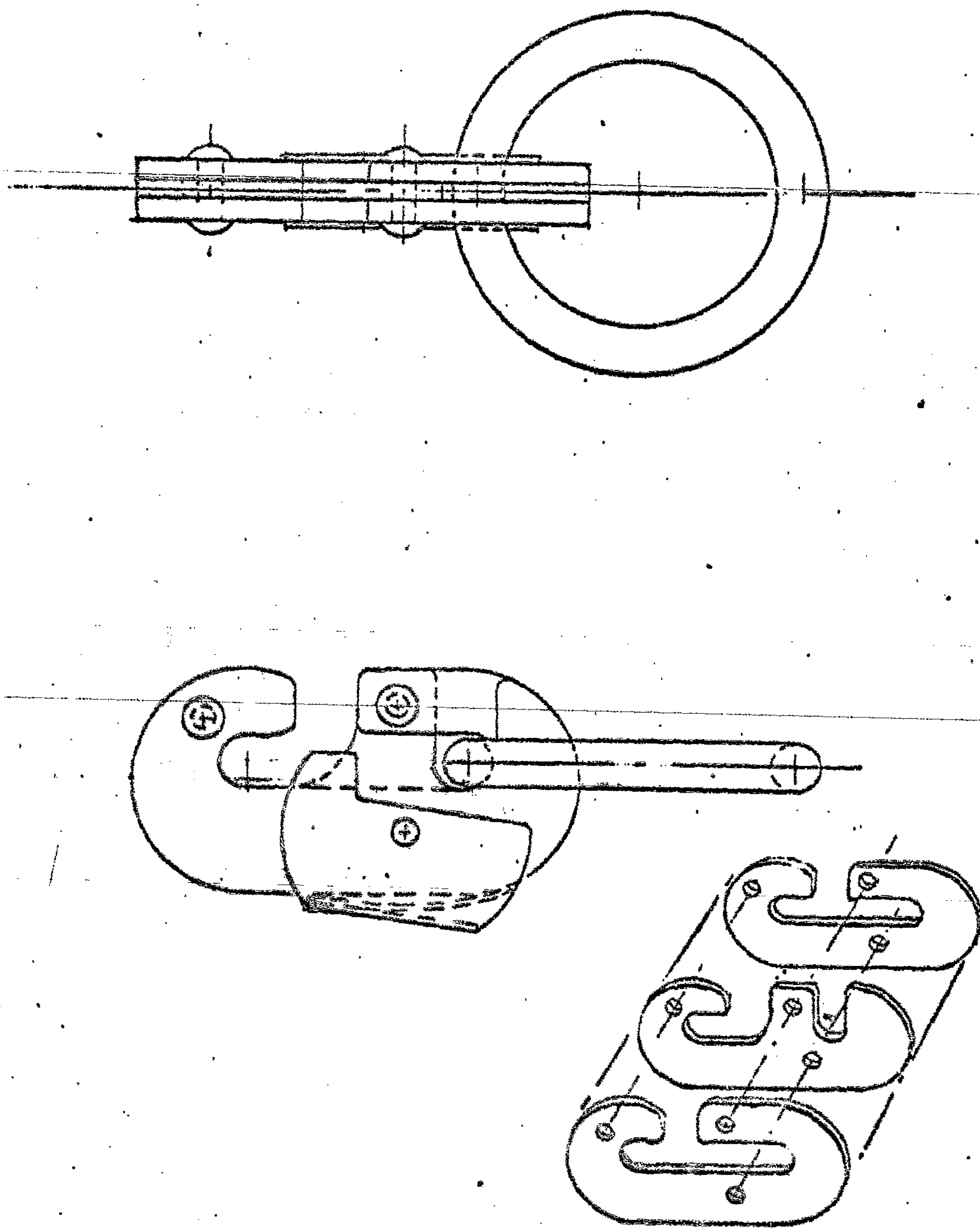




FIGURE F-25

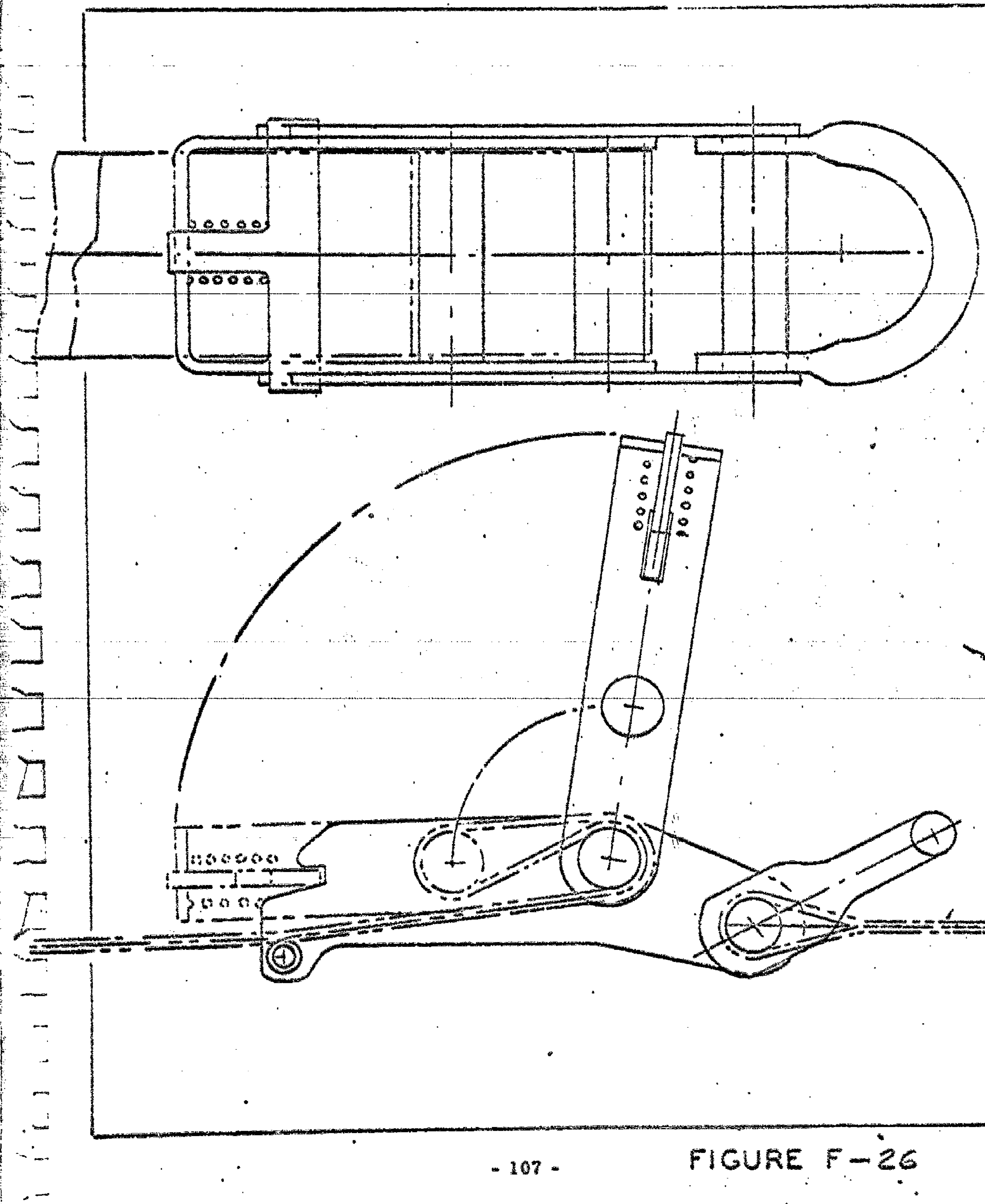


FIGURE F-26

## AIR-DROP PLATFORM DESCRIPTION

Figure 27 illustrates the design of an air-drop pallet recommended to comply with the objectives set forth in the Statement of Work. As shown, the pallet is a module with a basic size of 50" x 108", intended to be used with a 108-inch rail system.

The module construction consists of a core made from resin-impregnated paper honeycomb weighing approximately four pounds per cubic foot, bonded between two sheets of .063 7075-T6 aluminum alloy, the edges of which are bonded and riveted to the extruded members comprising the four edges of the pallet.

The 50-inch edges of the pallet are made from 6061-T6 aluminum alloy extrusion so designed in cross-section, as to provide a vertical restraint lip integral with two flanges for bonding the core facing to the extrusion. The flanges of the extrusion also provide attaching surfaces for the tie-down ring bushings. The vertical restraint lip is provided with notches at 10-inch spacing. The hollow portion of the extrusion is filled with balsa wood bonded to the paper honeycomb and to the extrusion.

The 108-inch edges of the pallet are made from two different extrusions one of which is a male member, the other being a female member. When two modules are joined together, the female edge of the pallet dovetails with the male edge of the adjacent pallet, the joint being held together by means of 3/8-inch diameter spring pins (roll-pin), on 6-inch centers. The resulting joint has the same mechanical properties as the modules which it joins. That is, when two or more modules are joined to form one continuous platform the assembly will act as if it were one continuous section with no decrease of stiffness and strength at the joint. Structural continuity of the module is also enhanced by the use of "L" shaped bracket at each of its four corners.

Tie-down ring sockets are provided at 6 - inch spacing along each 50-inch edge of the module to receive tie-down rings as required by the load configuration. Additional tie-down ring sockets could be installed along the 108" edges of the module to provide tie-down points not now available on the present modular air-drop platform.

In other respects this pallet is similar to the logistics pallet previously described. Weight of the module as will be found in the appendix.

Advantages and Capabilities

a. Minimum number of parts to store and handle; modules and spring pins only.

b. Integrity of structure made up of modules; no discontinuity of strength and stiffness at joints.

c. Maintainability; requires only the removal of spring pins to replace damaged module.

d. No sagging of adjacent panels to interfere with insertion of platform into rail/roller system; no special attention required to distribute load to eliminate sag.

e. Lowest cost item consistent with the designated test requirements of the Statement of Work.

f. Resistant to deterioration over world-wide climatic environments.

g. No special assembly orientation; no front/rear position relative to aircraft.

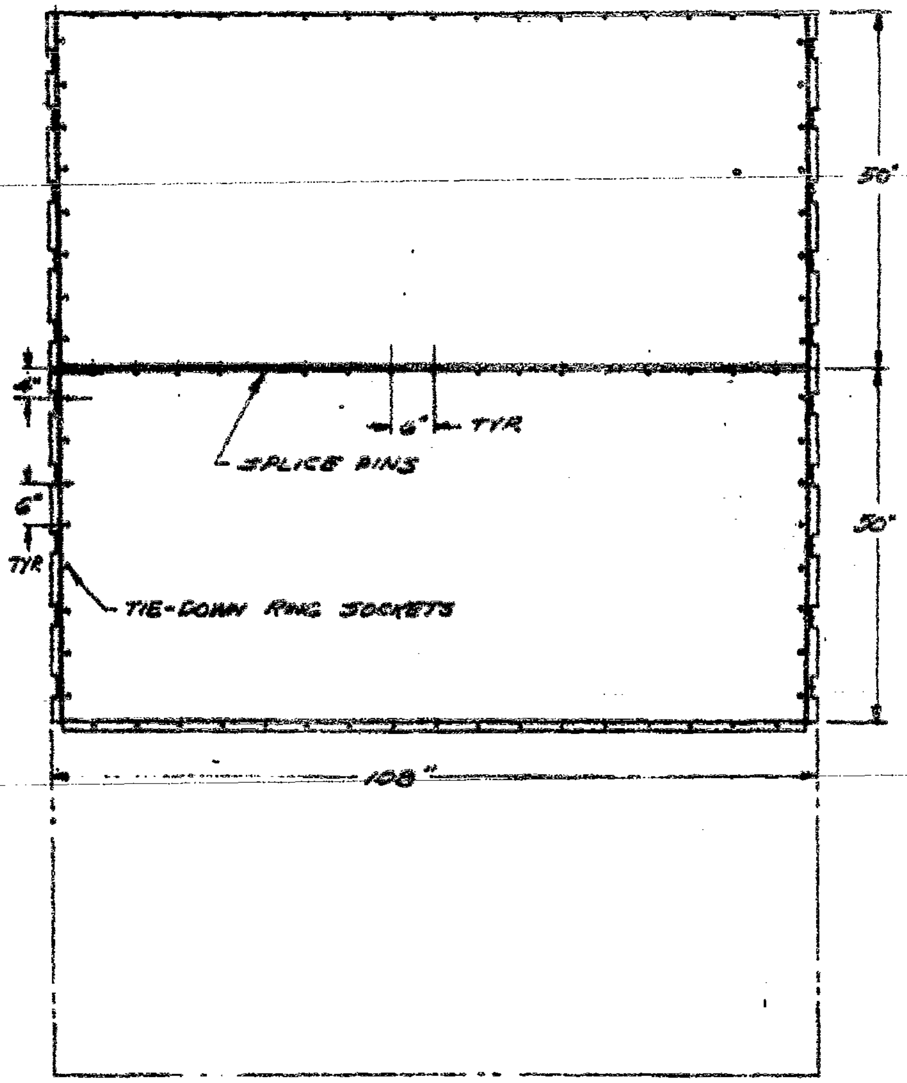
h. Thickness is only 2 1/4 inches.

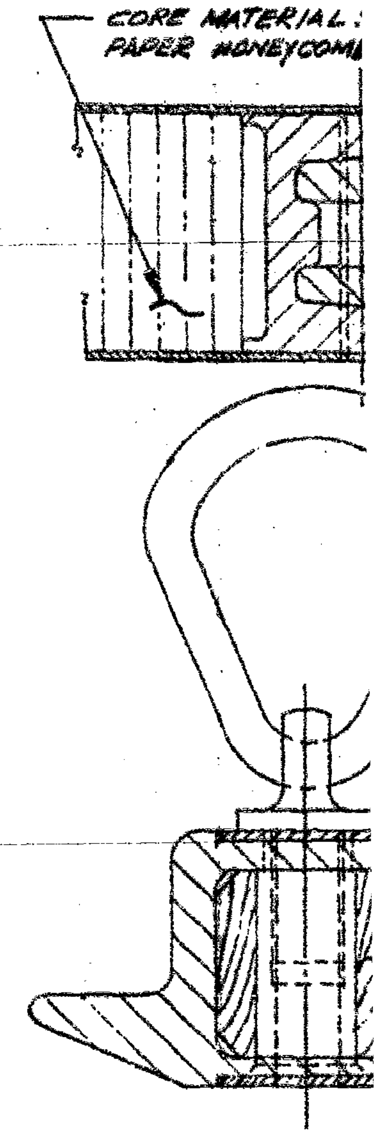
i. Meets the performance criteria specified in Exhibit 63-6.

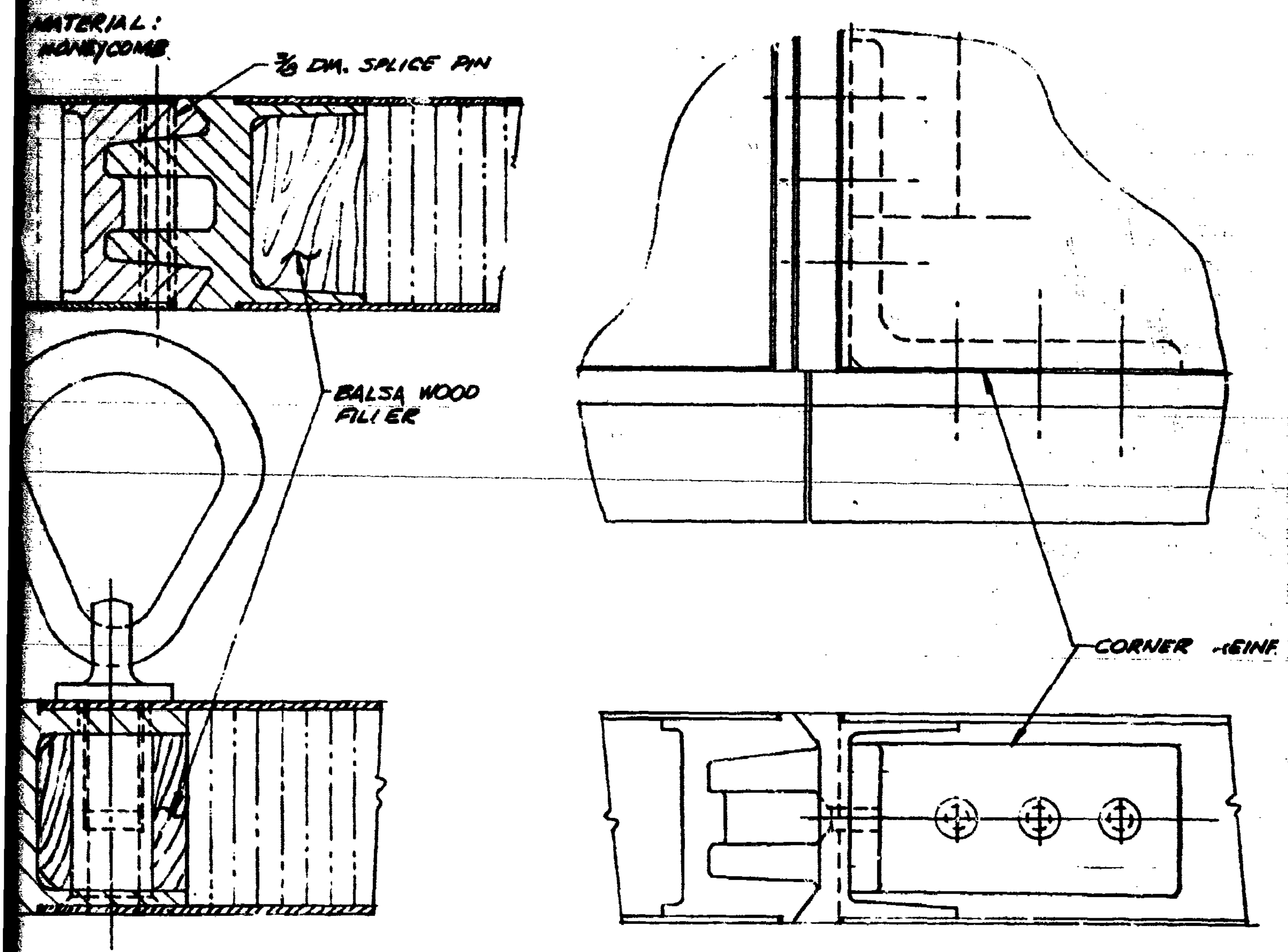
j. Uses currently available materials and fabrication techniques.

PROPOSED AIR-DROP PLATFORM

FIG. 27




MATERIAL:
HONEYCOMB
3/8 DIA. SPLICE PIN
BALSA WOOD
FILLER
CORNER REINF.

## LOW-LEVEL AIR-DROP PLATFORM

Figure 28 illustrates the design of the low-level air-drop pallet recommended to comply with the objectives of the Statement of Work. As shown, the pallet consists of one or more air-drop pallets of the construction previously described with the addition of the following components:

1. Nose-piece -

   The nose piece is constructed from a sheet of .090 6061-T6 aluminum alloy with 10 formed reinforcing ribs made from the same material riveted at equally spaced intervals along its breath. The two flanges at the open end are riveted to a length of female extrusion which is identical to that used in the construction of the air-drop pallet previously described. The extrusion is also connected to each of the 10 ribs by means of bolts which thread into captive nuts on the ribs. The lower surface of the nose sheet is provided with 3 joggled skirts the purpose of which is to prevent the entry of dirt and sand at the interface of the pallet and nose-block. The whole assembly is attached to the male edge of a standard air-drop pallet and held in place by means of 3/8-inch diameter spring pins.

2. Nose-block -

   The three nose blocks are made from 6-inch wide wedge shaped 6061-T6 aluminum alloy. The tapered end of the block slips into the joggled skirt of the nose piece and is equipped with a threaded insert to receive a 3/8-bolt passed through the joint of the pallet and nose piece. The rear of the block is machined to receive the forward end of the channel-shaped runner which is held to the block by a transverse 3/8 bolt.

3. Runner -

   The three runners are made from 6-inch channels, length being determined by the number of air-drop modules comprising the platform assembly. The leading end of each channel is connected to the nose block by a 3/8 bolt and at each succeeding module joint by another 3/8 bolt passed through the joint and into a solid block welded to the inside of the channel and equipped with a threaded insert.

The runners are spaced to allow loading with extraction of the platform without interference with the aircraft conveyor roller system.

Advantages

a. Additional 2 inches of length of pallet tends to reduce possibility of jamming during extraction.

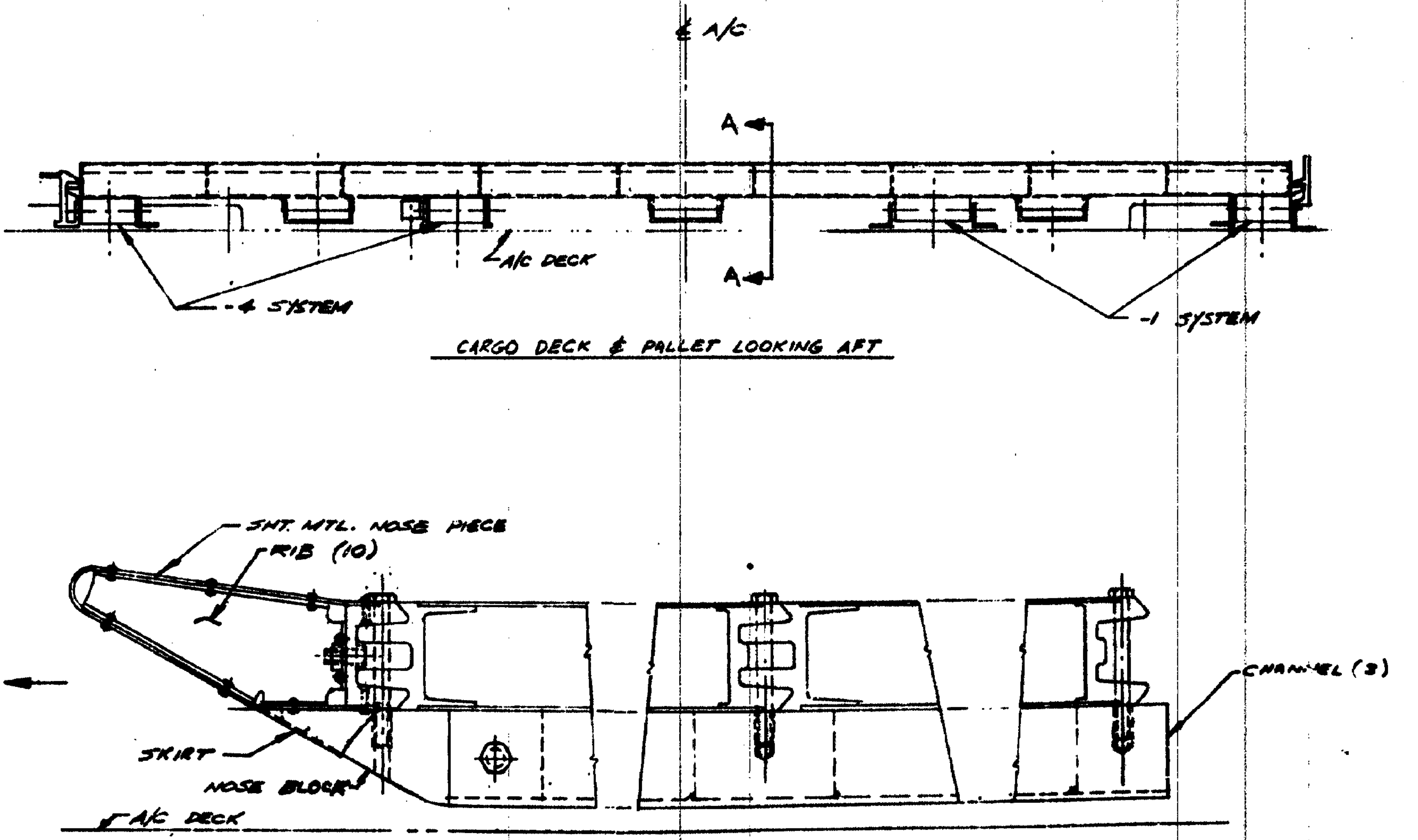
b. Construction enhances structural integrity of module/modules.

c. Three piece construction reduces repair and replacement cost and servicing time.

d. Can use proposed air-drop pallets without modification.

AIR DROP PLATFORM
MODIFIED FOR LOW LEVEL EXTRACTION

FIG. 28



EXTRACTION PARACHUTE LOAD TRANSFER DEVICE

The largest load air dropped to date is a 35,000 lb load. The extraction chutes that have been used to extract this load from the aircraft are a single 35 ft. or a cluster of two smaller chutes.

A study of the results of four different extractions of large loads indicate that actual recorded peak extractions force during the extraction were 38,600 lbs., 34,700 lb., 39,500 lbs., and 44,500 lbs. These forces were achieved just as the chute fully opens while still in tow. As the platform moves aft out of the aircraft the extraction force continually drops from the peak load to values about 25% less at the point of force transfer, see table below.

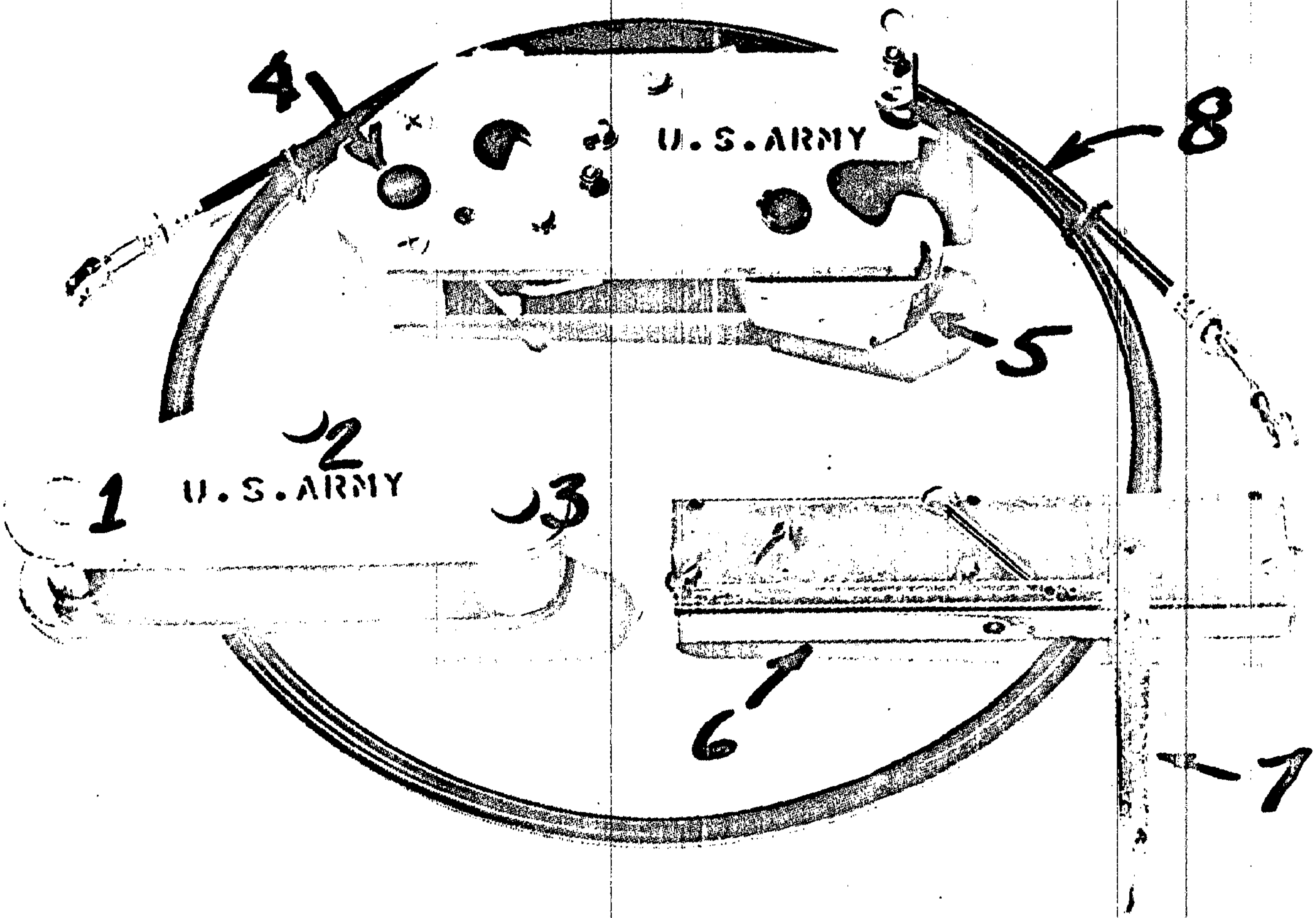
| | LOAD | PEAK EXTRACTION FORCE | FORCE AT TIME OF FORCE TRANSFER |
|---|---|---|---|
| 1. | 36,700 lbs. | 38,500 lbs. | 26,500 lbs. |
| 2. | 34,500 lbs. | 34,700 lbs. | 25,000 lbs. |
| 3. | 35,200 lbs. | 39,500 lbs. | 29,600 lbs. |
| 4. | 34,300 lbs. | 44,500 lbs. | 33,000 lbs. |

An extraction parachute load transfer device with a static load capability of 1-1/2 times the maximum extraction force of 45,000 lbs. which is equal to 67,500 lbs, and with the safety factor of 1-1/2 on the release force of 30,000 lbs. which is equal to 45,000 lbs. should be more than adequate for largest load dropped to date and for the forseeable future.

The device shown in Figure 29 was developed by Brooks & Perkins, Inc. and is currently being evaluated by the U.S. Army Natick Laboratories. The device has been tested statically to over 70,000 lbs. and has released successfully several times a test loads of over 50,000 lbs. Brooks & Perkins, Inc., therefore, recommends the adapting of this device for the Universal Air-drop Platform. Since the maximum air drop loads are and will be in the 35,000 lbs. range and since these loads constitute less than 5% of all air-drop loads it would not be economically feasible at this time to design a higher capability device, which would of necessity be larger, bulkier, heavier, more costly and more sophisticated due to increased part loadings. It would be much more practical and economical to use the recommended device as a "one time" use item for these large loads, if it is felt that the device presented a risk after a release at the above loads.

The transfer device can be mounted directly to the load or to the platform. Figures 30 and 31 show an adaptor bracket that can be fastened to the aft end of the platform. The attachment is accomplished by slipping the bracket into the platform extrusion and securing with the same spring pins that are used to fasten the platform modules together. Figure 32 shows the means of adapting the trigger assembly to the universal air-drop platform and the modified arm for use with the -4 rail system.

Figure 29





- 116 -

TECHNICAL ANALYSIS FORM

| | | |
|---|---|---|
| BY E. MAREA DATE 6-25-65<br>CK. ______ DATE ______<br>REV. ______ DATE ______ | BROOKS & PERKINS<br>b+p<br>DEFENSE PRODUCTS DIVISION | SHEET ______ OF ______<br>SUBJECT ______ |

## ADAPTER BRACKET - EXTRACTION PARACHUTE LOAD TRANSFER DEVICE PLATFORM MOUNTING

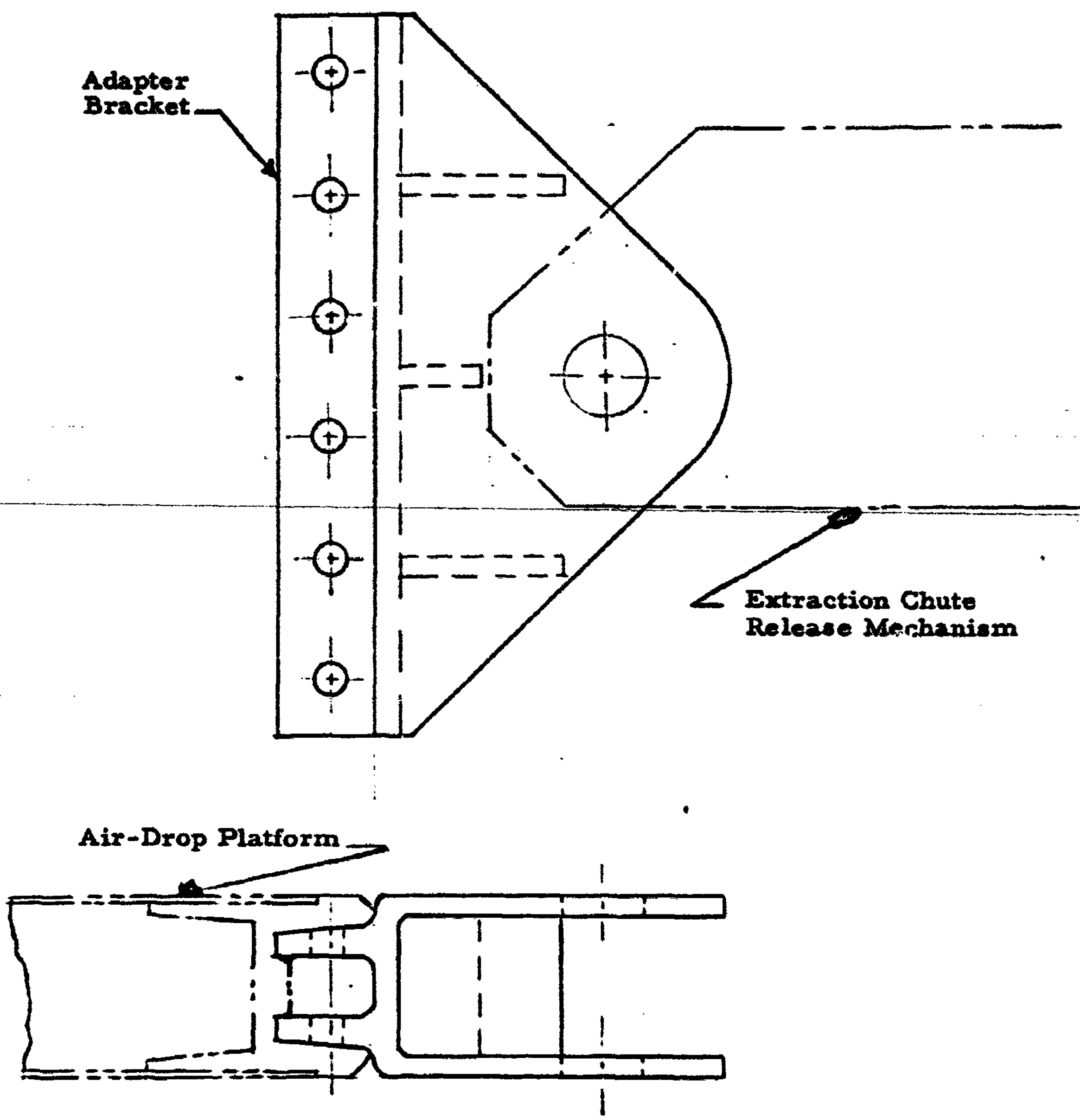



Figure 30

MATERIAL:
7075-T6 Forging

TECHNICAL ANALYSIS FORM

| | | |
|---|---|---|
| BY____ DATE____ | BROOKS & PERKINS | SHEET____ OF____ |
| CK____ DATE____ | b-p | SUBJECT____ |
| REV.____ DATE____ | DEFENSE PRODUCTS DIVISION | |

ADAPTOR BRACKET ASSEMBLED TO PLATFORM

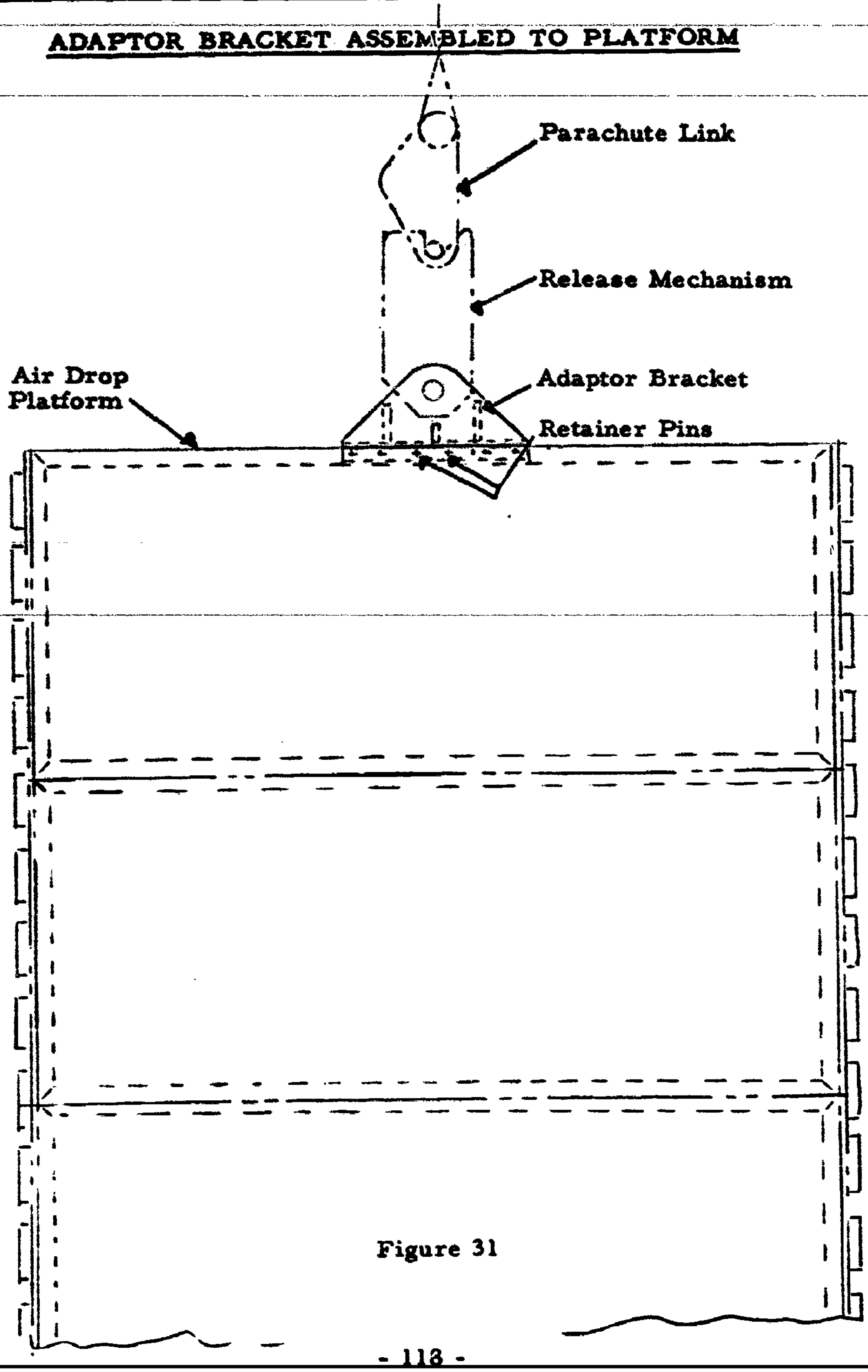
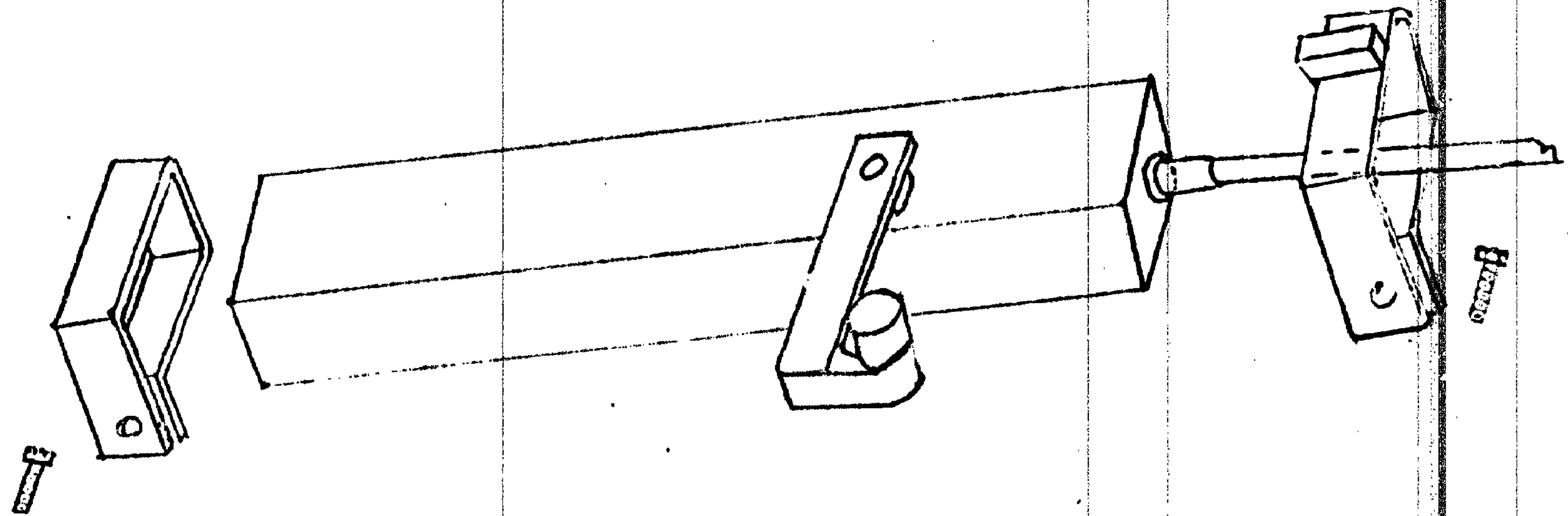



Figure 31



ADAPTING RELEASE TRIGGER DEVICE ASSEMBLY
TO PLATFORM AND THE -4 RAIL CONFIGURATION.

Figure 32

# APPENDIX I

# GENERAL APPROACH TO DETERMINATION OF OPTIMUM AIRDROP MODULE SIZE

## APPENDIX 1

### GENERAL APPROACH TO DETERMINATION OF OPTIMUM AIRDROP MODULE SIZE

### OBJECTIVE

It is desired to find if there exists a definite "optimum" airdrop module length. In addition, it is desired to ascertain the sensitivity of the degree of optimality to variation in the module size.

### APPROACH

Rigging instructions exist for most current standard airdrop loads. From these rigging instructions the load length, $L_L$, and minimum allowable platform length, $L_m$, are extracted. It is assumed that the current distribution of differences between $L_L$ and $L_m$ is at least representative of the distribution of such differences as the mix of airdrop equipment changes over the next few years. A general expected value approach is set up and the expected length loss is determined for four module lengths. No weighting according to importance is applied to any equipment item. Redundant data (e.g., different loads rigged inside a 1/4-ton truck) was omitted.

### OPTIMUM SIZE DETERMINATION

Figure A1 shows the occurrence of the minimum[1] required platform lengths for a number of important standard loads. As can be seen by the figure, these lengths are fairly evenly spread over the range from below 75 to over 300 inches.

Interaction between the minimum length required and the overall load length is important in determining cargo space utilization. Figure A2-a shows a schematic airdrop load.

The difference between the load length, $L_L$, and the minimum platform length required, $L_m$, is called delta, $\Delta$, as shown by Figure A2-b. No loss of aircraft cargo compartment length may occur if $\Delta$ is larger than the module length, M. This is true because if $\Delta$ is larger than the module length, any module length required must necessarily fall under the "overhang" of the load, where no other platform may be placed.

- - - - - - - - - - -

[1] "Minimum required" lengths are based on the observation that all loads require enough platform to accommodate the honeycomb shock absorbing material plus some extra length for sufficient tie down angle. A minimum length of between 100 and 110% of the length required for the honeycomb appears to satisfy this requirement and consequently is used. Load lengths are taken as overall equipment length, or, when necessary equipment plus parachute platform, etc.

SOURCES: TM 10-500-Series for Rigging Airdrop Loads

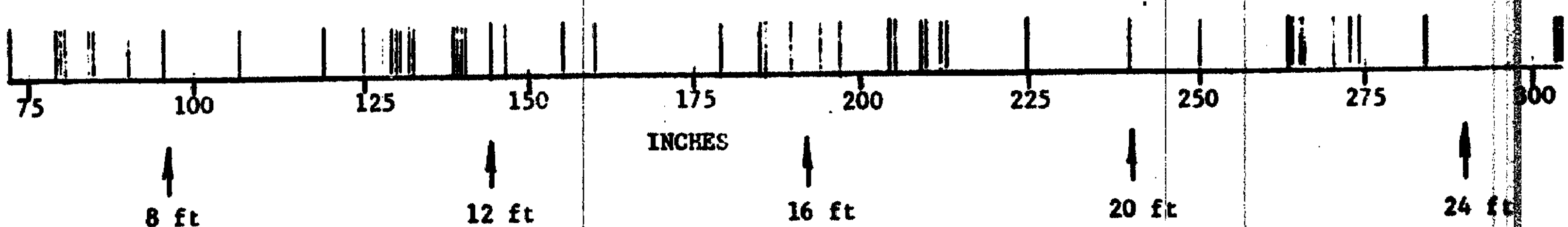



Figure A1. Occurrence of "Minimum Airdrop Load Lengths"
(See text for explanation of "minimum")

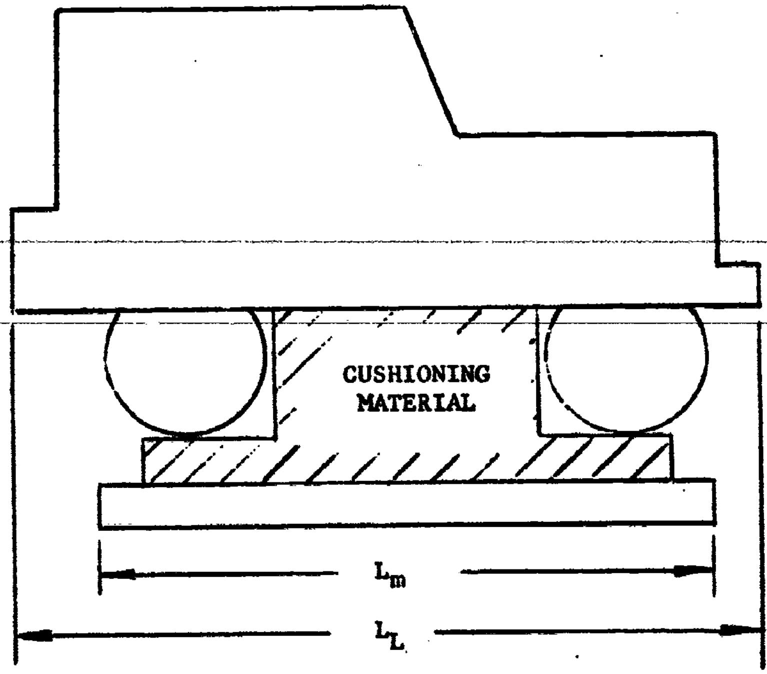



Figure A2-a. Sketch of Airdrop Load Dimensions

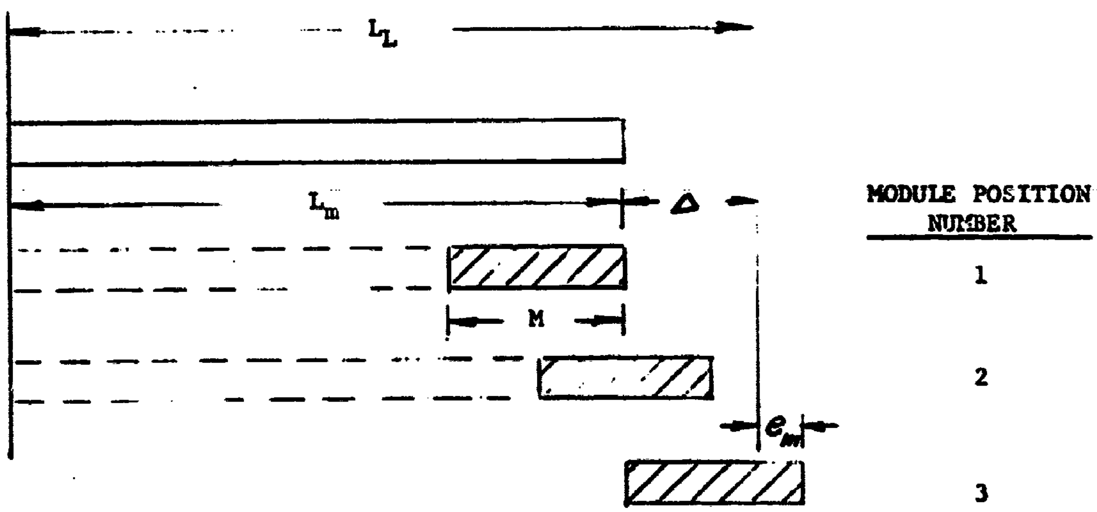



Figure A2-b. Sketch of Platform-Module Relationships

When M is greater than $\Delta$ some loss may occur. In order to get an idea of the relative order of magnitude of this loss for different module lengths, the following calculation was made.

For some unspecified load-module combination, we can see that if we are very fortunate in making up the platform, it will exactly fit the length required, as in position 1 of Figure A2-b. Much more likely is the situation shown in position 2, in which the necessary number of modules exceeds the required length.

As mentioned above, however, no loss occurs until the end module extends past the load length. Position 3 shows the maximum amount of such loss, called $e_m$. As is evident from the figure $e_m$ equals $M - \Delta$.

In the general case, we may consider that it is equally likely that the edge of the end module falls anywhere between $L_m$ and $L_m + M$. Consequently, we see that any loss at all is expected to occur $e_m/M$ percent of the time. When this loss occurs, its average will be $e_m/2$ since we have assumed uniform positional as likelihood.

Figure A3 may then be used to interpret this result with current standard airdrop loads that have delta greater than a specified size.

Let us consider the 44-inch module. Figure A3 shows that this module length fits 22% of airdrop loads with no loss ($\Delta$ greater than M); hence, a loss in aircraft space utilization is possible for 78% of the loads. In this range, the value of $\Delta$ varies reasonably linearly. The value of $e_m$ should therefore vary from 44 to zero inches as delta varies from zero to 44 inches.

An expected loss of 7 inches results for a 44-inch module. The average load length of the standard loads shown in Figure A3 was 196 inches. The 7-inch expected loss due to "pallet overhand", then, represents only 4% of the available cargo compartment space.

It is interesting to compare the length loss with a module length as small as 29-1/3 inches, which may be taken as a lower limit of reasonable length. With the above approach, space loss should drop to an expected value of 4 inches, a "gain" of only 3 inches, or 2%, over the 44-inch size. It is evident, therefore, that airdrop load length loss caused by module overhang is small in this size range and is relatively unaffected by module size.

A similar calculation was made for 48 and 88-inch length platforms. The results for all four sizes may be summarized as follows:

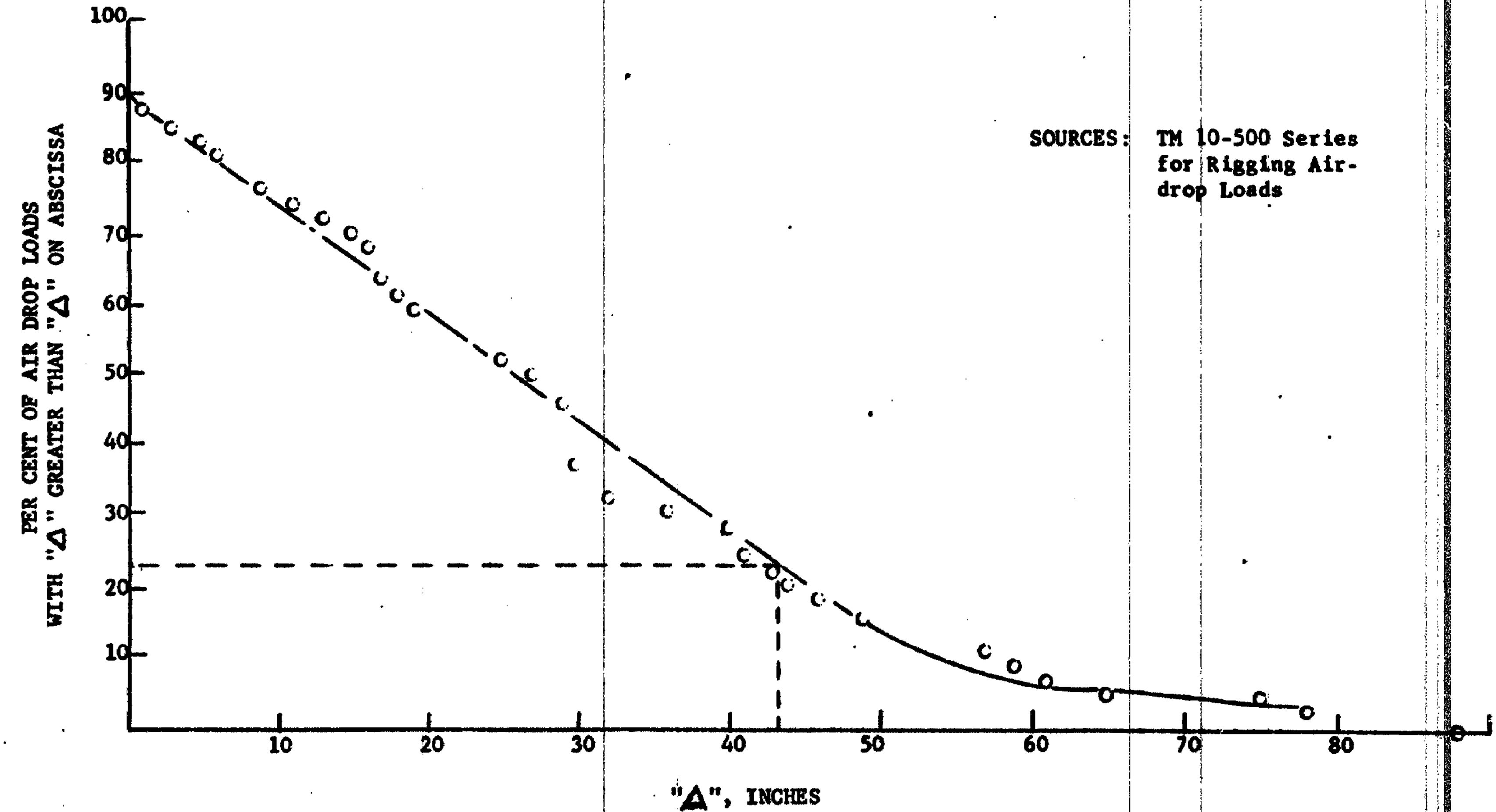



Figure A3. Occurrence of "Δ", or Difference Between Load Length and Minimum Length, for a Number of Airdrop Loads

| Module Length | Expected or Average Space Loss (Inches) | Expected Space Loss (%) |
|---|---|---|
| 29-1/3 | 4 | 2 |
| 44 | 7 | 4 |
| 48 | 8 | 4 |
| 88 | 16 | 8 |
| 50 | 10 | 5 |

# APPENDIX II

## SPECIFIC EQUIPMENT LIST APPROACH TO DETERMINATION OF OPTIMUM AIRDROP MODULE SIZE

## APPENDIX 2

## SPECIFIC EQUIPMENT LIST APPROACH TO DETERMINATION OF OPTIMUM AIRDROP MODULE SIZE

### OBJECTIVE

It is desired to find the effect of airdrop platform module length on the efficiency of fitting airdrop platforms to a specific list of airdrop equipment.

### APPROACH

An equipment list for a ROAD airborne division (TOE 57E) was used as a typical example of a specific airdrop equipment mix. Load length and minimum platform length were tabulated for each item. The fit of several possible module systems was investigated.

The analysis in Appendix 1 is a general approach to the effect of different airdrop module lengths on the utilization of available aircraft space. The results of that analysis may be summarized as follows:

1. Loss of aircraft length due to assembled platforms "overhanging", or extending past the length of airdrop loads, is small--in the order of 4% of total platform length for a 44-inch module.

2. This overhang loss is relatively insensitive to drastic reduction in module length; halving the 44-inch module size produces a loss reduction of less than 3% in terms of the total platform length.

3. The small overhang loss is likely to be insignificant in comparison with other aircraft utilization factors--platform spacing required by the rail size, "grossing out" of aircraft, fitting of assembled platforms into the aircraft, etc.

The calculations that resulted in the above conclusions were based, however, on the assumption that airdrop level dimensions were not known exactly, and that loads and load overhangs could be approximated sufficiently by present data. More important, the specific loads in the data were unweighted. For example, the 1/4-ton utility truck data were treated in the same manner as were data for road graders. Since the composition of equipment in future airdrops is not exactly known, this approach provides a useful general indication of the affect of module size on aircraft utilization.

It is of interest, however, to consider an airdrop movement with specified quantities of specific equipments, and to ascertain whether the above results apply in such a situation.

OPTIMUM AIRDROP MODULE LENGTH FOR A SPECIFIC DIVISION AIR EMPLACEMENT

Table A-I shows the number of major items of equipment for initial air emplacement of a ROAD Airborne Division (TOE 57E)[1]. Equipment items which would be airlifted in quantities fewer than 10 are omitted. Table A-I includes 4429 out of a total of 4506, or 98% of the equipment items. Overall load length and "minimum platform length" are shown. Minimum platform length is based on the overall length of the shock absorbing paper honeycomb patterns specified in the U.S. Army TM 10-500 series, which covers rigging of airdrop loads. In some cases, up to 110% of the honeycomb length is considered the minimum platform length in order to provide sufficient platform length for a reasonable tie down pattern.[2]

The data in Table A-I are plotted in Figure A4. Each shaded block represents the range of desirable platform lengths for the equipment item corresponding to the number beside the block. The shaded areas are arranged in order of the relative importance, or number carried, of the corresponding equipment items. Figure A4 shows how well a particular airdrop module system meets the size of the important loads.

A transparent "overlay" on which are drawn lines representing the platform lengths that may be achieved with a particular module could be placed on this figure. The optimum module length would provide an overlay grid of platform lengths that intersect each of the shaded blocks of the major items of equipment. If a platform length line does not fall through the shaded blocks, a platform length corresponding to the line next to the block on the right must be used. The scaled difference between the right end of the block and the next line would represent the amount of platform that will extend out from under that particular equipment item. This amount represents a potential loss of aircraft space, though not necessarily a real loss. Figure A4 and a series of overlays could be used to search for a "perfect" platform length. However, since module and platform size are bound by many practical constraints, the evaluation will be limited to module lengths proposed elsewhere.

- - - - - - - - - -

1 Based upon an USCONARC Strategic Airlift Requirements unofficial planning report.

2 Restrictions limiting allowable overhang of the platform by the equipment were not applied in each case. Current rules-of-thumb, e.g. keeping the angle between the end of the platform and the extreme point of the load greater than 30°, were checked in several instances, however. Overhangs implied by the shaded area in Figure A4 were well within the allowable amount in each case checked.

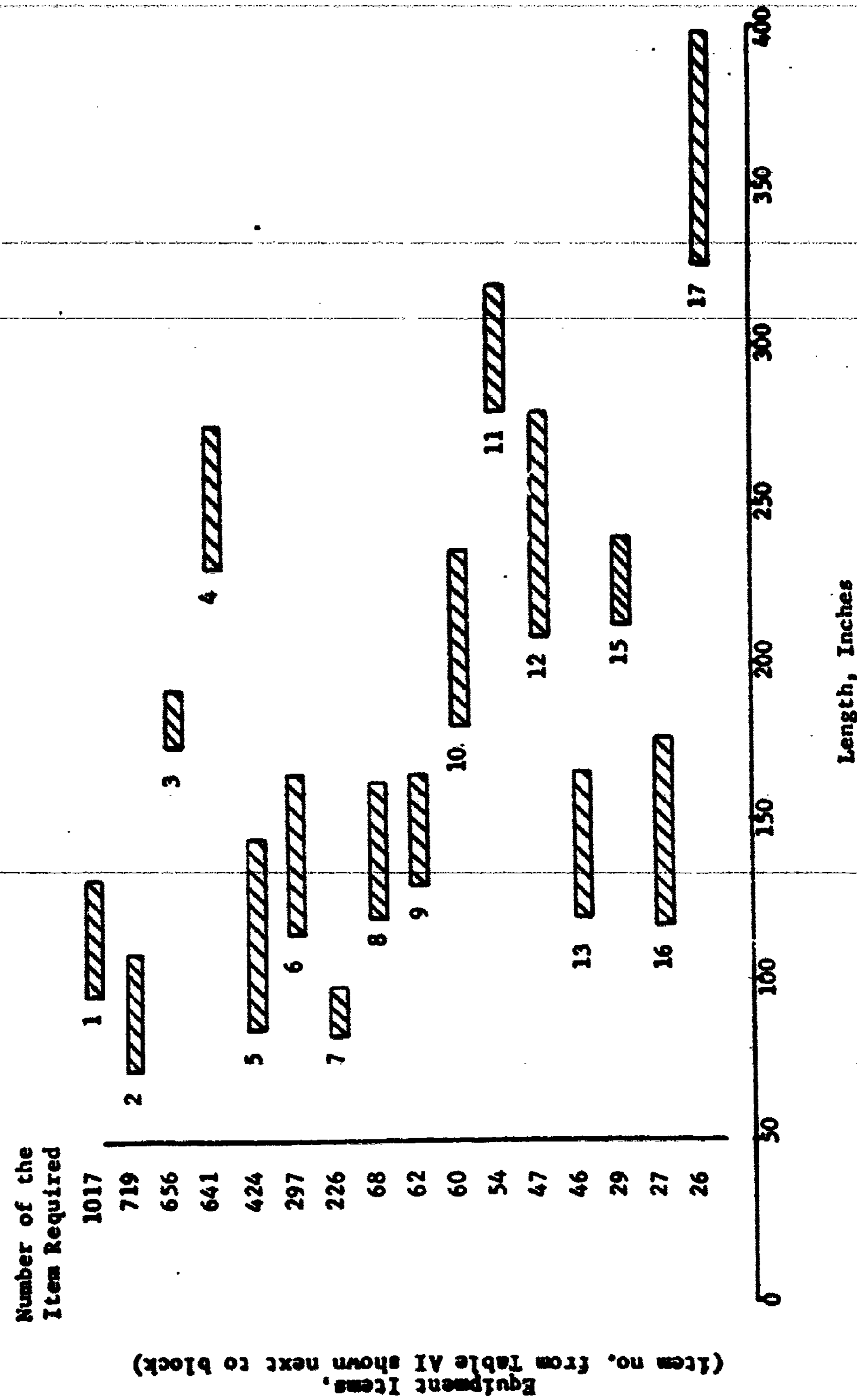



Figure A4. Ranges of Desirable Lengths for Airdrop Platforms for Major Equipment Items, Airborne Division

## TABLE A-I

### MAJOR EQUIPMENT ITEMS REQUIRED FOR AIRLIFT FOR AN AIRBORNE DIVISION, TOE 57E (ROAD)

| Item No. | Number Required | Equipment Item | Load Length[1] (in) | Minimum Platform Length[1] (in) | Length of Modular Platform Currently Used |
|---|---|---|---|---|---|
| 1 | 1017 | 1/4-ton Utility Truck | 132 | 96 | 144 |
| 2 | 719 | 1/4-ton Cargo Trailer | 109 | 72 | 96 |
| 3 | 656 | 3/4-ton Truck (var. configurations) | 192 | 174 | 144 |
| 4 | 641 | 2-1/2-ton Truck (var. configurations) | 276 | 230 | 288 |
| 5 | 424 | 3/4-ton Cargo Trailer | 147 | 86 | 144 |
| 6 | 297 | 1-1/2-ton Cargo Trailer | 166 | 114 | 144 |
| 7 | 226 | 1/2-ton Mule M274 (two) | 98 | 83 | 96 |
| 8 | 68 | 1-1/2-ton Trailer, water | 163 | 120 | 144 |
| 9 | 62 | 1/4-ton Ambulance M170 | 165 | 130 | 144 |
| 10 | 60 | 105 MM Howitzer & Carrier | 236 | 180 | 192 |
| 11 | 54 | 75 MM Gun & Carrier | 319 | 280 e | n.a. |
| 12 | 47 | 90 MM Tank M56 | 278 | 208 | 240 |
| 13 | 46 | 1-1/2-ton Ammo. Trailer | 166 | 120 e | n.a. |
| 14 | 30 | 3-ton Warehouse Platform Trailer | n.a. | n.a. | n.a. |
| 15 | 29 | Armored Personnel Carrier | 239 | 212 | 240 |
| 16 | 27 | 2-1/2-ton Engr. Utility Trailer | 176 | 118 | 144 |
| 17 | 26 | 5-ton Truck (var. configurations) | 399 | 325 e | n.a. |
| TOTAL | 4429 | | | | |

[1] Sources: U. S. Army TM 57-210, TM 10-500 series
"e" - indicates estimated, not based on TM 10-500

Figure A5 shows the relationship of the present 108" x 48" Army modular platform to the airborne division equipment shown in Figure A4. The series of lengths possible with this system fit all of the major equipment loads without significant aircraft space loss.

Two proposed platforms are illustrated in Figures A6 and A7. Figure A6 shows lengths corresponding to a system of 108" x 44" modules. The figure indicates that this module length fits all equipment items with approximately the same degree of effectiveness as the present module.

The 108" x 88" basic module plus a 108" x 50" add-on module is illustrated by Figure A7. This combination fits all major equipment items without loss except the 1/4-ton truck (Item No. 7). This truck could be rigged satisfactorily on two 50-inch modules (100" total length), if such an assembly were part of the system.

On the other hand, if a 138-inch module is used for rigging a 1/4-ton truck, the loss of aircraft space is still relatively small. Figure A7 indicates that a 138-inch long platform exceeds the length of the 1/4-ton truck by 6".[1] Since there are 1017 such trucks in a division-lift, as indicated by Table A-I, the possible aircraft length loss amounts to 6101 inches. However, the total length of all the loads listed in Table A-I is 738,488 inches. Consequently, misfitting the 1/4-ton truck by 6 inches amounts to a loss of less than 1% of the total length. This 1% may be compared to another space loss--required gaps between platforms. The 108" x 88" plus 50" add-on system never requires more than a 2-inch gap in order to match the side-rail detents. When a minimum gap is desired, the 108" x 44" and 108" x 88" systems may be expected to require an average spacing of about 5 inches. When platforms are required to be placed close together, therefore, the 108" x 88" plus 50" add-ons system would be superior.

Figures A8 and A9 show the relationship of the airborne equipment loads to systems consisting of 108" x 29-1/3" and 108" x 88" modules. The shorter module fits all equipment items with no aircraft loss. This size, however, has been eliminated previously. The 88" long module produces a loss on several equipment items. The sum of this length loss for the airborne division equipment listed in Table A-I amounts to 64,546 inches out of the total 738,488 inches required. This is almost a 9% utilization loss.

- - - - - - - - - -

[1] This depends in actuality upon which 1/4-ton truck is used. According to U.S. Army TM 57-210 and the appropriate TM 10-500, 1/4-ton truck lengths are as follows:

| | |
|---|---|
| M-38 - 133 in | M151 - 132 in |
| M-38A1 - 139 in | M170 - 155 in |

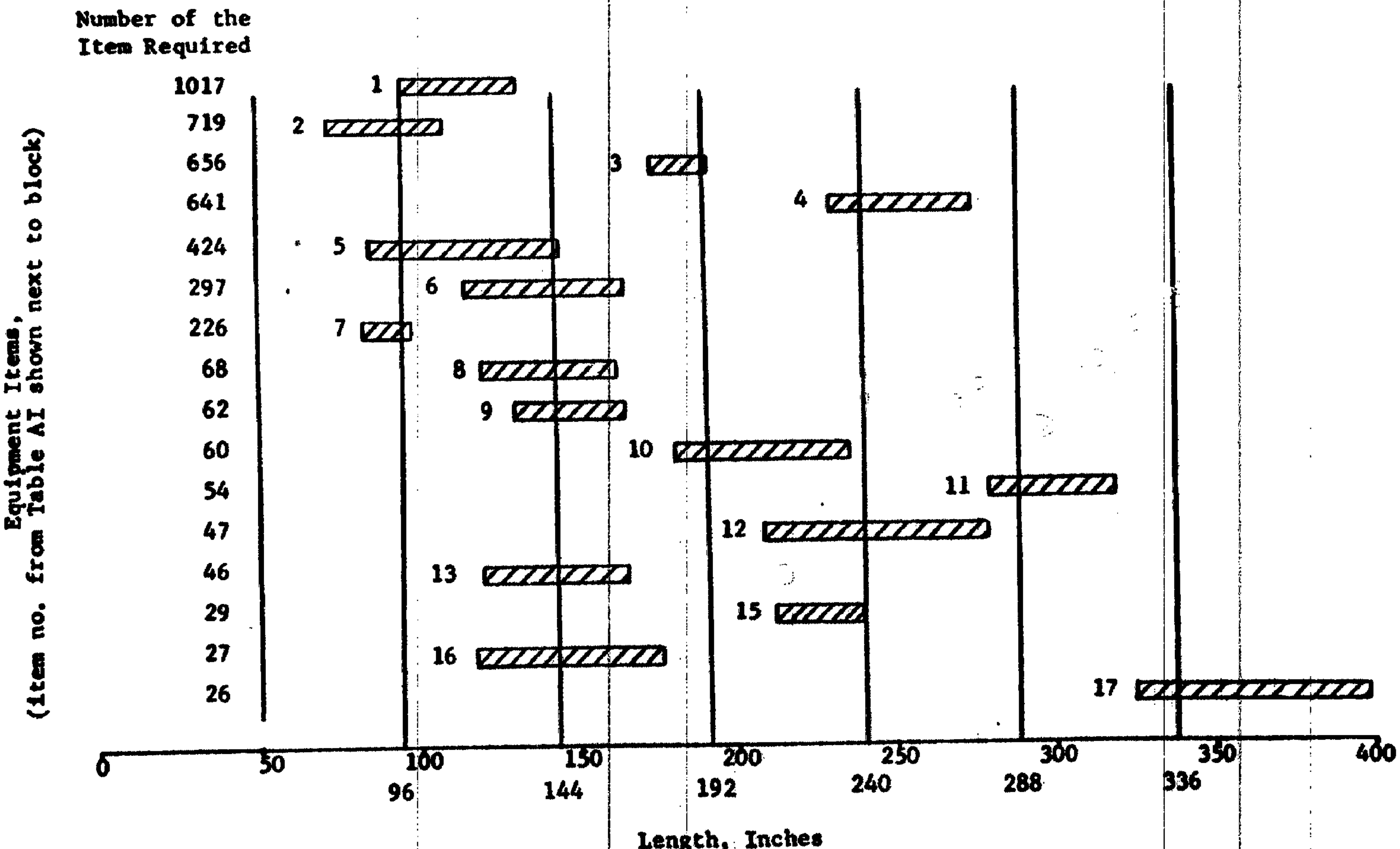



Figure A5. Relationship of Airdrop Platform Lengths for Airborne Division Equipment to the Present 48" Modular Platform

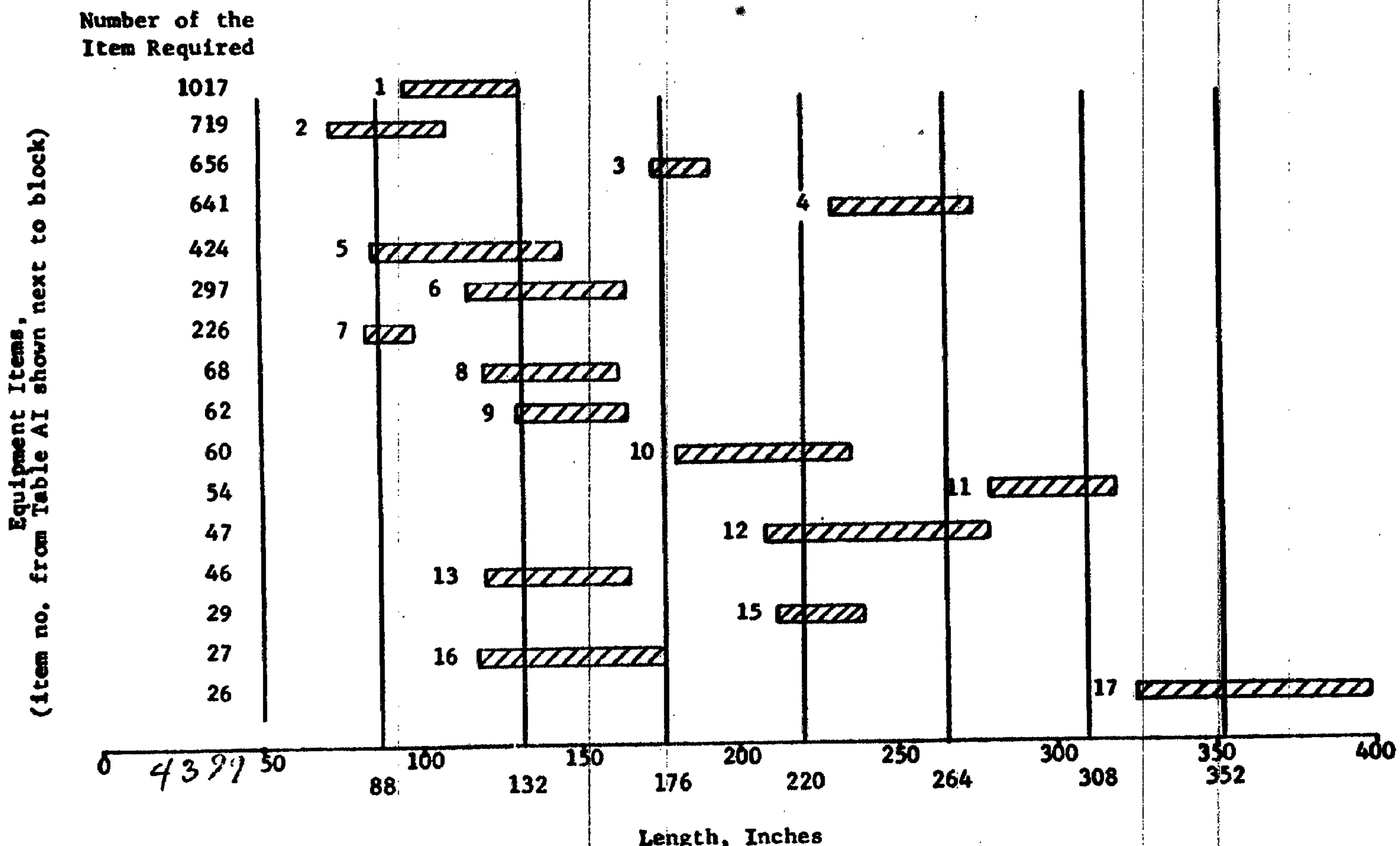



Figure A6. Relationship of Airdrop Platform Lengths for Airborne Division Equipment to a 108" x 44" Modular Platform System

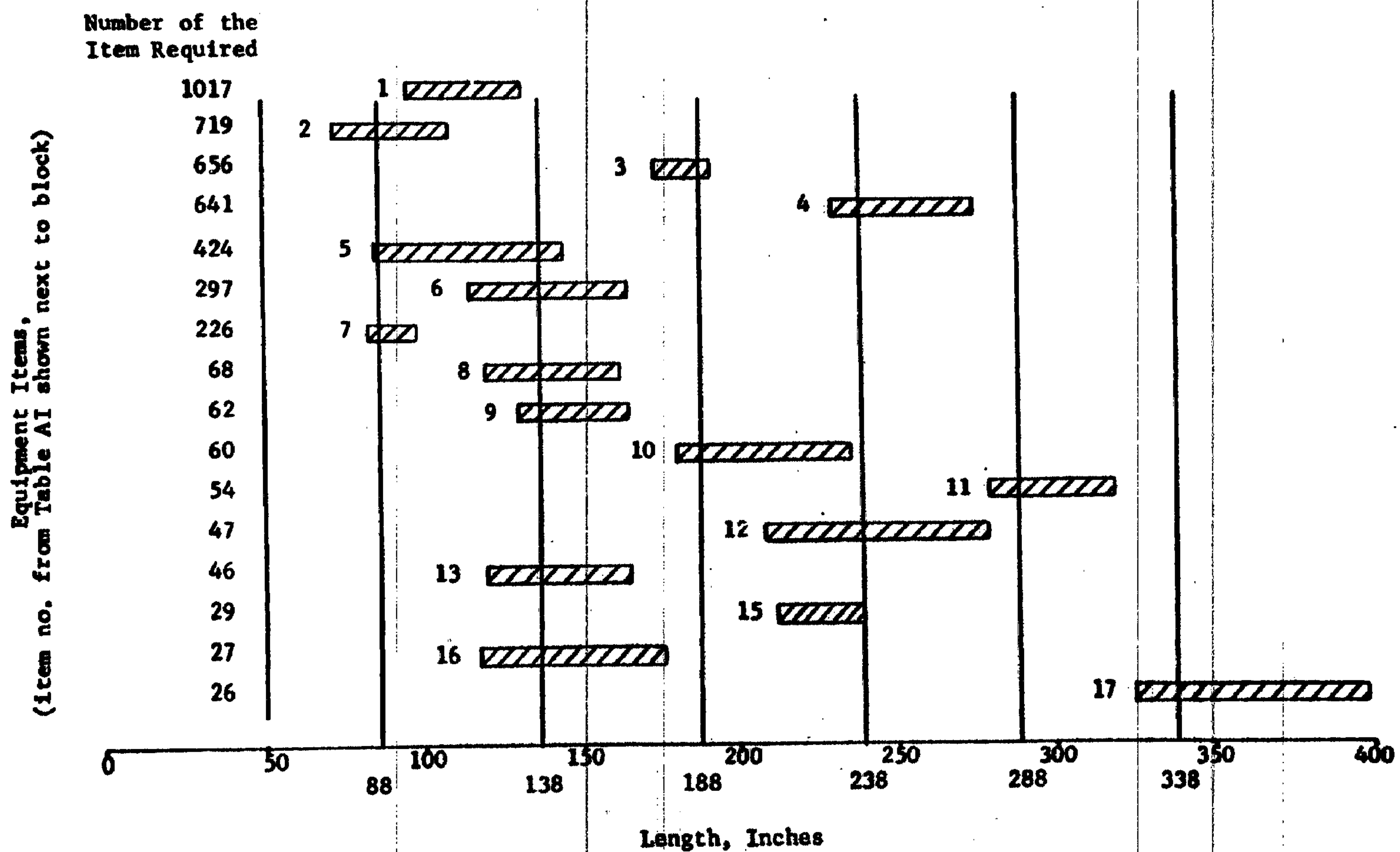



Figure A7. Relationship of Airdrop Platform Lengths for Airborne Division Equipment to a Basic 108" x 88" Module with 108" x 50" Add-on Sections

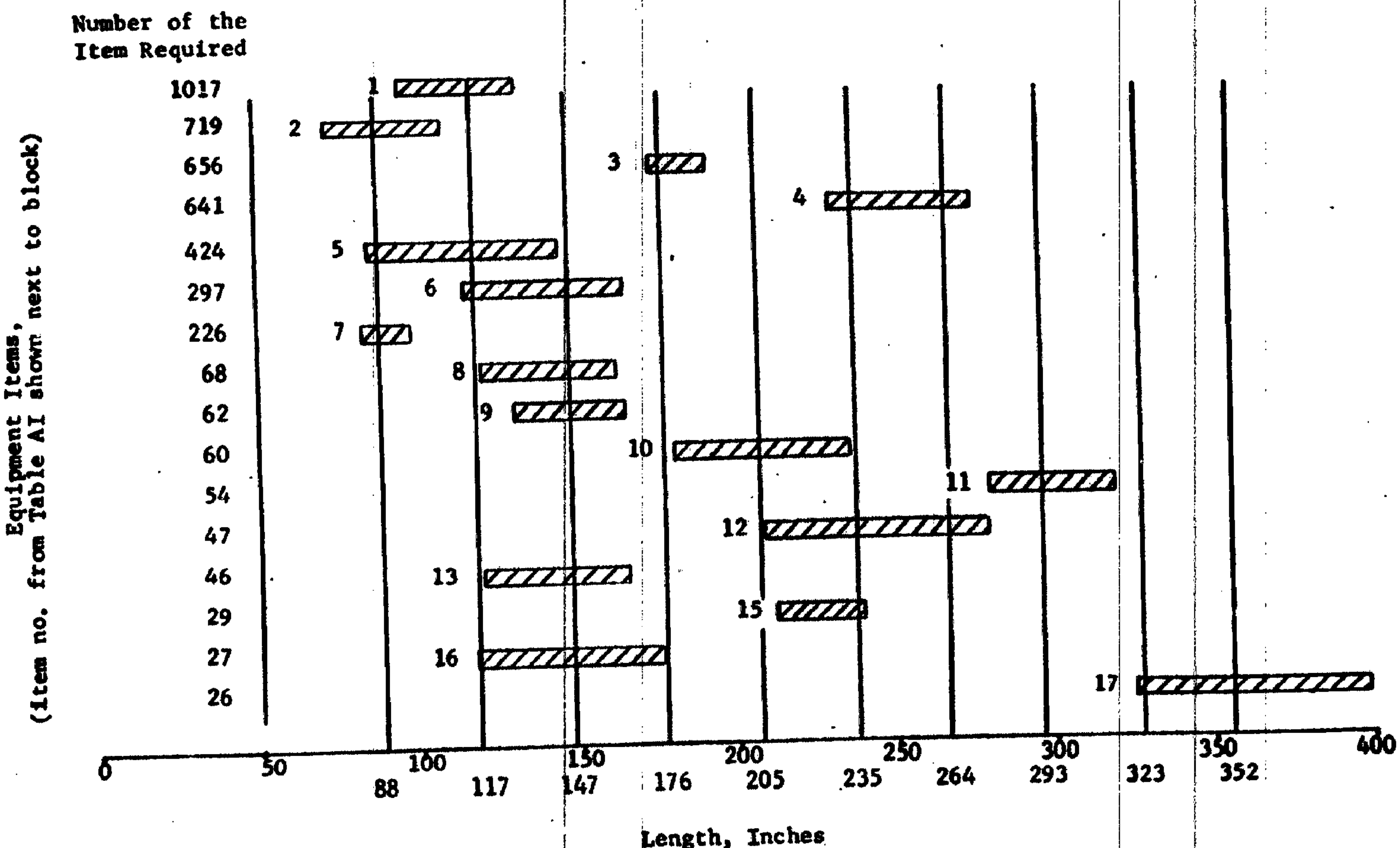



Figure A8. Relationship of Airdrop Platform Lengths for Airborne Division Equipment to a 108" x 29-1/3" Modular Platform System

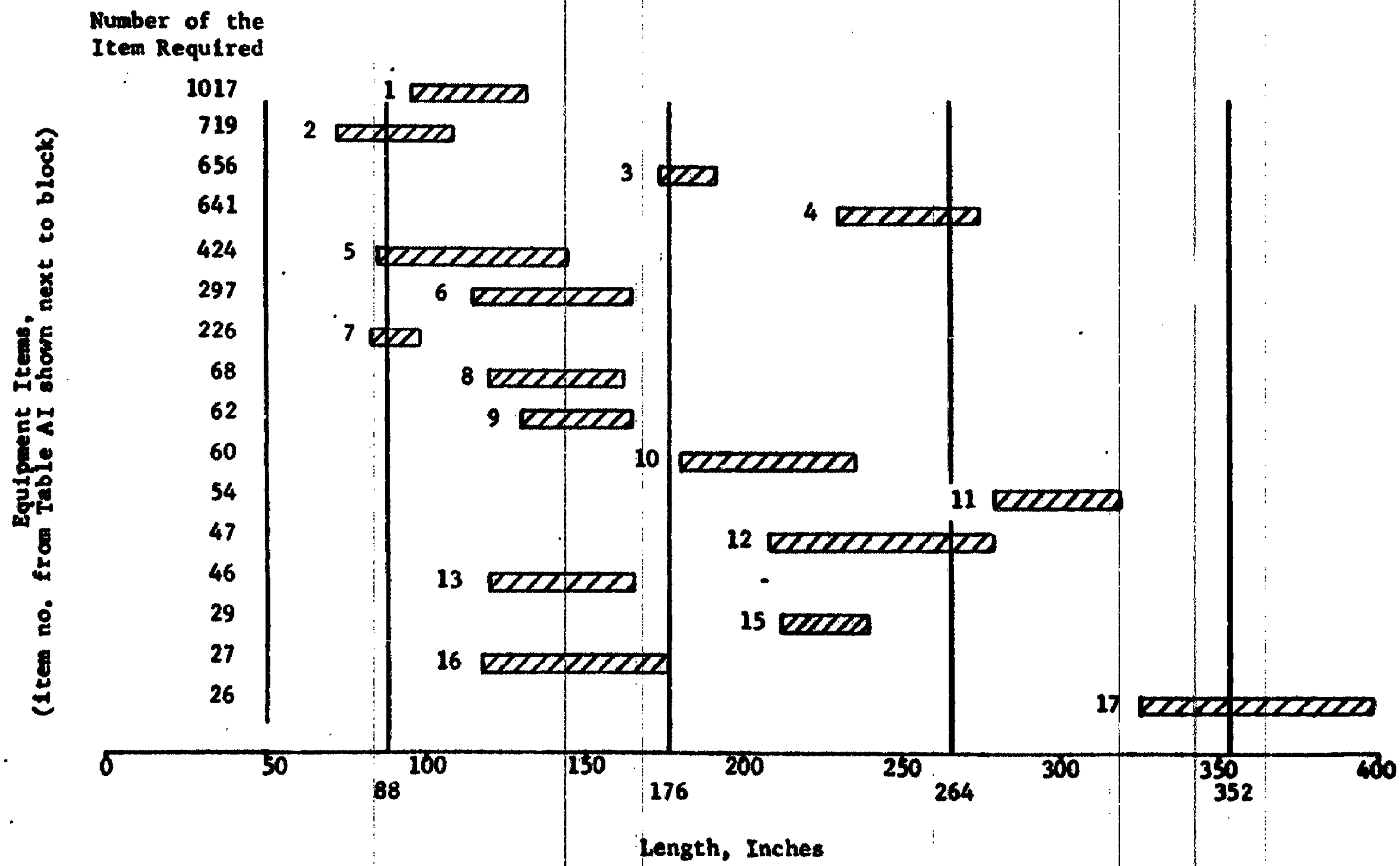



Figure A9. Relationship of Airdrop Platform Lengths for Airborne Division Equipment to a 108" x 88" Modular Platform System

The above analysis leads to the conclusion that there is no significant difference in initial airdrop load length matching between the 29-1/3", 44", 48" and the 88" basic module with 50" add-on. The 88" length increment provided by the 108" x 88" system results in a poor fit of the important airborne division loads, thus producing an aircraft space loss of approximately 9%. Although the TO&E for the airborne division will undoubtedly change from time to time, the above results should apply for a reasonable degree of change in equipment allocations.

# APPENDIX III

## PLATFORM COSTS PER TRIP

Light weight, long life and low initial cost are desirable features of an air cargo platform.

All three of these features are of interest to the extent that they contribute to a lower cost per trip for the platform. For example, if a platform's cost is reduced by 1/4, this would appear to be desirable. If in the process the useful life is reduced by half, however, the cost per trip has been increased.

A combination of cost, weight, and life that produces the minimum cost per trip is the real objective. To find this minimum, however, it would be necessary to have a complete understanding of how the useful life varies with the cost and weight, for example, or how weight changed with different cost and endurance. Since these relationships are highly dependent on design, materials, and production methods, it is difficult to find a meaningful relationship between weight, cost, and endurance. It is possible, however to investigate the marginal value of improvements in pallet characteristics.

We may assume a "reference" platform of the following characteristics.

| | |
|---|---|
| Weight: | 290 lbs. |
| Cost: | $250 |
| Endurance: | 180 trips (average) |

We may then evaluate the relative desirability of improvement in these reference characteristics in terms of cost per trip.

Cost per Trip

If a platform has a purchase cost, P, and a useful life of N trips, and a weight, W, the cost per trip C, is simply:

$$C = \frac{P}{N} + W (A)$$

Where A is a constant which expresses the freight cost per lb. incurred in one trip using a platform. For military overseas air cargo, this value is taken to be 0.13$ per lb. per trip. The reference platform has a cost per trip, therefore, of:

$$C\ ref. = 250 + 290\ (0.13)$$

$$C\ ref. = \$1.40 + \$38.70 = \$39.10 \text{ per trip}$$

Increase in Useful Life

What is the value of an improved platform that has a greater useful life?

Figure III-1 shows that increasing the platform life has little effect on the cost per trip. This is because the weight counts for such a large proportion of the cost per trip. An increase in N of 100 yields a reduction in cost per trip of only 1.3%.

Similarly, the cost per trip equation shows that reducing the platform cost to $150 could not reduce the cost per trip below $38.50, or by more than 1.5%. One may conclude, therefore, that the cost per trip of the reference platform is relatively insensitive to increases in useful life or reduction in purchase cost.

The reduction in cost per trip with decreasing weight is more significant. Figure III-1 also shows that a reduction in weight of 100 lbs. reduces the cost per trip to $26.10, a reduction of 33%.

Conclusion

A decrease in the weight of the reference platform tends to reduce the cost per trip more than does a decrease in cost or an increase in platform life.

CALCULATION OF AIRFREIGHT COST PER POUND OF CARGO PLATFORM

A value is desired for the average airfreight cost per pound of military air cargo platform in overseas service.

The following values may be taken:

- average distance of loaded trip - 6,000 miles
- average return trip distance - 6,000 miles
- average air gas cost - \$.20/gallon
- average jet fuel cost - \$.08/gallon
- marginal fuel consumption per ton of cargo, prop. aircraft - 0.7 gal/ton-mile
- marginal fuel consumption per ton of cargo, j et aircraft - 0.6 gal/ton-mile
- total freight cost in prop. aircraft - .15 \$/ton-mile
- total freight cost in jet aircraft - .10 \$/ton-mile

When an additional pound of platform weight is carried, one of two cost occur:

a. If the aircraft is not loaded to maximum weight, extra weight consumes more fuel; marginal fuel costs apply.

b. If the aircraft is at full weight, full freight charges must be applied to extra platform weight.

At present, few MATS cargo flights are "grossed out". Military cargo density trends are toward heavier cargo, however, and during emergencies heavier (25 lbs/ft.$^3$ ) Army cargo would be carried in greater proportion. In addition, most of the newer jet cargo aircraft are designed with higher cube/lb. capacity. Consequently, we will assume a future overseas air cargo fleet of 40% propeller aircraft and 60% jets, which will be carrying capacity cargo 25% of the time, on the average. Return trips are assumed to all be at less than aircraft capacity.

Average freight costs per pound of cargo platform are, therefore:

$$\text{Cost/lb.} = \left[(.75)(12{,}000) + (.25)(6{,}000)\right]\left[(.60\ \frac{(.06)}{(2000)}\ (.08) + (.40)\frac{(.07)}{(2000)}\ (.20)\right] + (.25)(6000)\left[(.60)\ \frac{(.10)}{2000} + \frac{(.50)(.15)}{2000}\right]$$

Cost/lb. = 0.1345 \$/lb. per 6000-mile trip

We will, therefore, use a figure of 0.13\$ per lb. as the freight costs per lb. of platform weight per trip.

TECHNICAL ANALYSIS FORM

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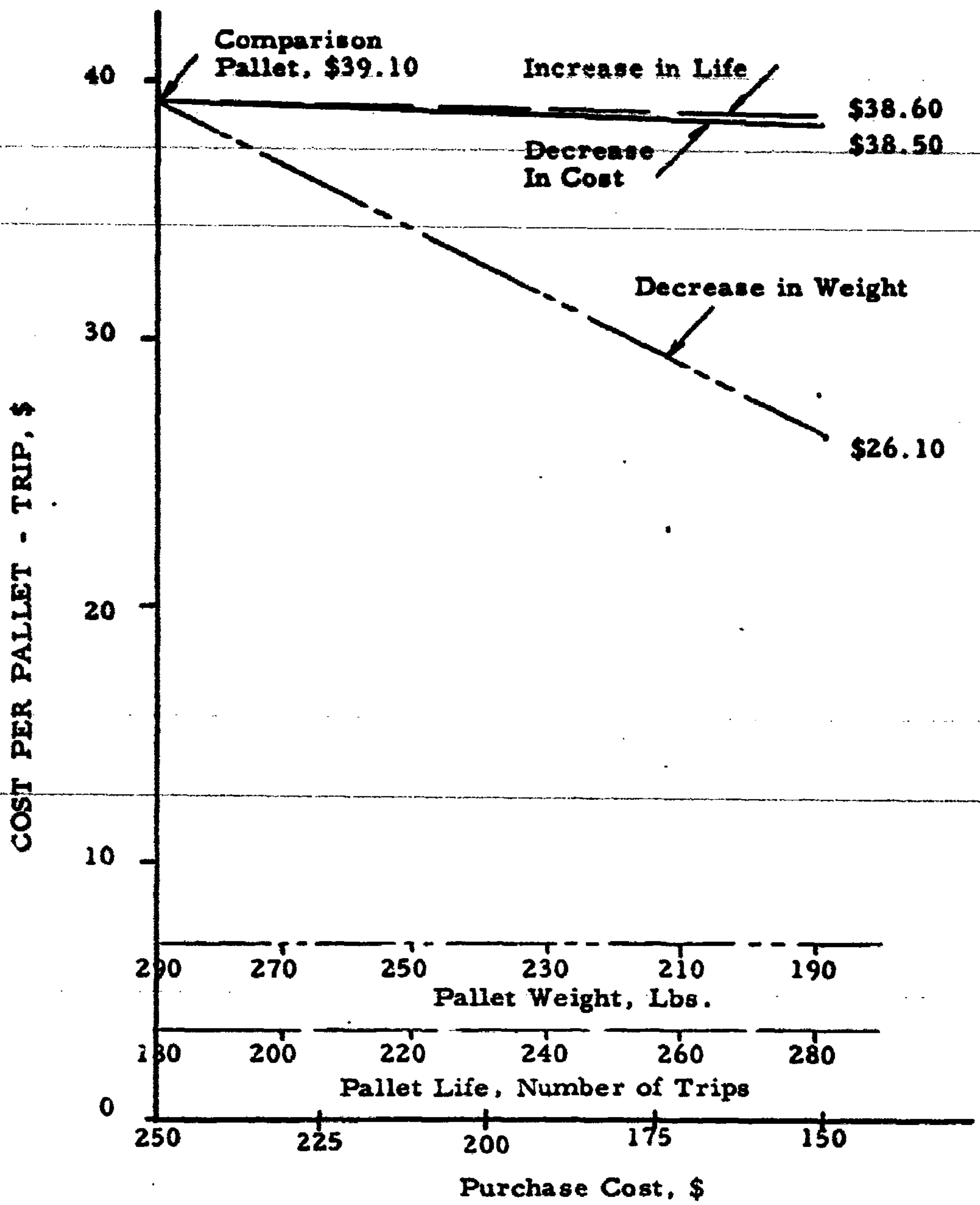
FIGURE III-1




EFFECT ON COST PER TRIP OF IMPROVING COST, LIFE AND WEIGHT OF AN AIR CARGO PALLET



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# APPENDIX IV

# PALLET STRESS CALCULATIONS

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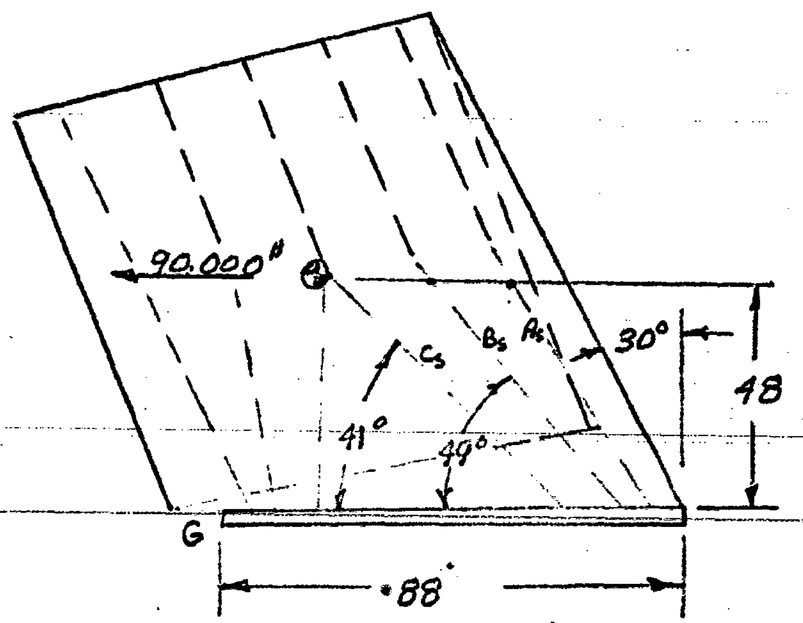
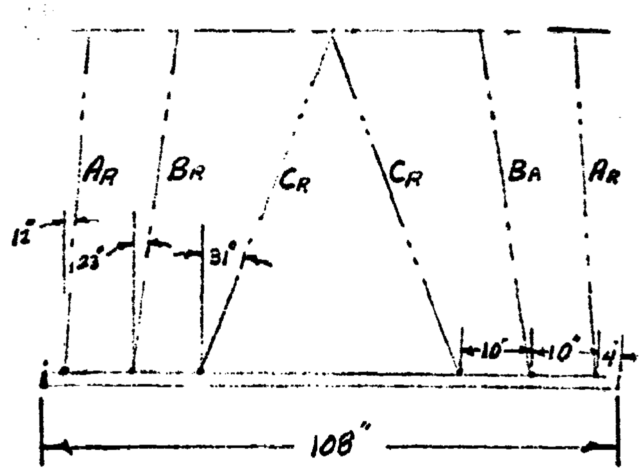
RESTRAINT ATTACHMENT FITTINGS ARE LOCATED AT 4", 14" & 24" INBOARD FROM EACH OF THE CORNERS ALONG EACH EDGE OF THE PALLET. THE WEBBING MEMBERS WERE SELECTED SO THAT WHEN AT THE 4 INCH LOCATION A 10,000 LBS APPLIED A 6000 LBS IS AT 14" & 4000 LBS AT 24".



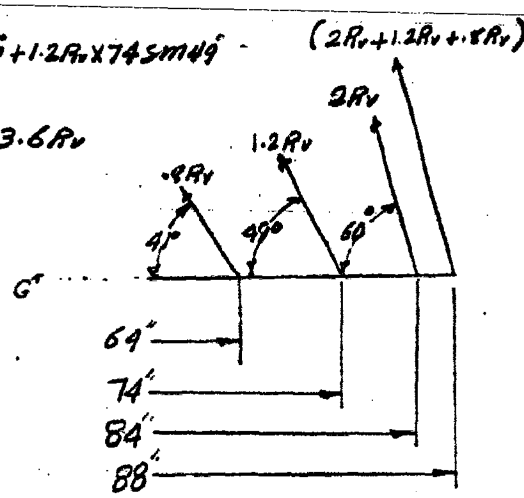
ASSUME VERTICAL LOADS AT REAR EDGE ARE IMPOSED BY WEBS $A_R$, $B_R$ & $C_R$. AT SIDE BY WEBS $A_S$, $B_S$ & $C_S$.
ASSUME $R_V$ LBS BE THE VERTICAL LOAD AT WEBS $A_R$ & $A_S$
∴ $.6R_V$ & $.4R_V$ ARE THE LOADS ON WEBS $B_R$, $B_S$ & $C_R$, $C_S$.

MOMENT @ POINT G:

$$90{,}000 \times 48 = 4R_V \times 88 \sin 60^\circ + 2R_V \times 84 \sin 60^\circ + 1.2R_V \times 74 \sin 49^\circ + .8R_V \times 64 \sin 41^\circ$$

$$4{,}320{,}000 = 304R_V + 145R_V + 66.9R_V + 33.6R_V$$

∴ $R_V = 7860$ LB.

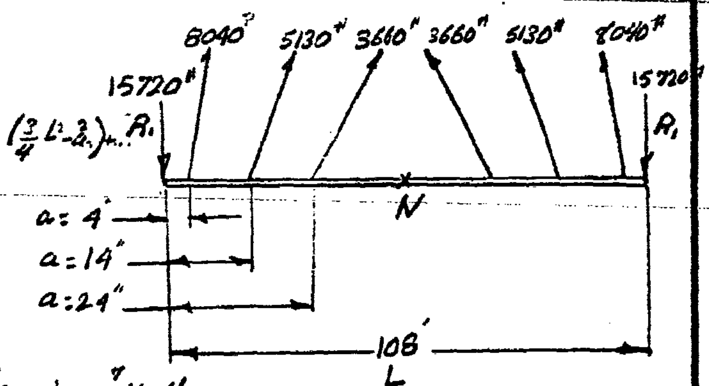



∴ $R_{AS}$ = 7860 LB
$R_{BS}$ = 4720 LB
$R_{CS}$ = 3140 LB
& $R_{AR}$ = 8040 LB
$R_{BR}$ = 5130 LB
$R_{CR}$ = 3660 LB

DEFLECTION AT POINT N

$$EI\frac{d^2y}{dx^2} = M = M_1 + M_2 + M_3$$

$$\therefore EI\,y = \frac{P a_1}{6}\left(\frac{3}{4}L^2 - a_1^2\right) + \frac{P_2 a_2}{6}\left(\frac{3}{4}L^2 - a_2^2\right) + \ldots$$




EI = D STIFFNESS

$$D = \frac{E_f\, b\,(t^3 - t_c^3)}{12} + (EI)_{EXTR.}$$

$$= 10^7 \times 20\,(2.25^3 - 2.13^3)/12 + 10^7 \times .4$$

$$= 3.28 \times 10^7$$

$$DY = 8040 \cos 12 \times \frac{4}{6}\left(\frac{3}{4} \times 108^2 - 4^2\right) + 5130 \cos 23 \times \frac{14}{6}\left(\frac{3}{4} \times 108^2 - 14^2\right) + 3660 \cos 31 \times \frac{24}{6} \times \left(\frac{3}{4} \times 108^2 - 24^2\right)$$

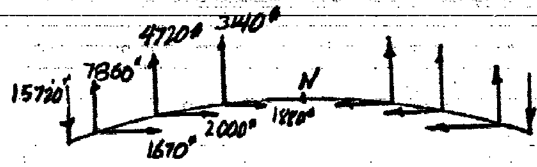
$$\therefore 3.28 \times 10^7\, Y = 45{,}800{,}000 + 94{,}300{,}000 + 103{,}000{,}000$$

∴ $Y = 7.4"$

BENDING MOMENT @ POINT N

$M_{MAX} = 15720 \times 44 - [40 \times 8040 \cos 12 + 30 \times 5130 \cos 23 + 20 \times 3660 \cos 31]$
$+ 7.4 \times 8040 \sin 12 + 4 \times 5130 \sin 23 + 2.5 \times 3660 \sin 31$
$= 691,680 - 518,600 + 25050$
$= 202,130$ IN-LB.

MAX. FACING STRESS $= \dfrac{M_{MAX}}{b\, t_c\, t_f}$




ASSUME $t_f = .063"$
$\therefore t_c = 2.250 - 2 \times .063$
$= 2.124"$
$b = \frac{2}{9} L$
$= \frac{2}{9} \times 88$
$\approx 20"$

$\therefore f_f = \dfrac{202,130}{20 \times .063 \times 2.124}$
$= 75500$ P.S.I.

MATERIAL : 7075-T6
$F_{tu} = 77,000$ P.S.I.
$F_{cu} = 77,000$ P.S.I.

$M.S. = \dfrac{77,000}{75,500} - 1$
$= +.019$

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WEIGHT VS. SANDWICH THICKNESS:

PAPER HONEYCOMB WT. 3.9 LBS/CU.FT.
VOLUME OF HONEYCOMB = H.W.L
L = 105.875" ; W = 85.875" ; H = VARIABLE
WT. OF HONEYCOMB = 105.875 X 85.875 X H X 3.9/1728
= 20.5 H LBS.
VOLUME OF SKIN = t.W.L.
L = 105.5 ; W = 85.5 ; t = VARIABLE
WT. OF SKIN = 105.5 X 85.5 X t X .1 X 2
= 1810 t LBS.

$$f_t = \frac{M_{MAX}}{20\, H_c\, t_f}$$

$f_t$ = 75,500 P.S.I SEE P. 3
$M_{MAX}$ = 202,130 IN-LB SEE P. 3

∴ $H_c$ = 202,130 / 20 X 75,500 X $t_f$
$H_c$ = .134 / $t_f$

EXTRUSION WT = S.t.h.X.1
= 383.5 X .25 X .1 X h
= 9.6 h LBS

| SKIN THICK. | HONEY. THICK. | SKIN WT | HONEY WT. | SUB TOTAL WT. | EXTR. h | EXTR. WT. | TOTAL WT. | SANDWICH THICKNESS |
|---|---|---|---|---|---|---|---|---|
| .025" | 5.36" | 45.25# | 109.8# | 155.05 | + 2.01 | + 19.3 | 174.35 | 5.41 |
| .032 | 4.19" | 57.90# | 86.0# | 143.90 | + .84 | + 8.06 | 151.96 | 4.25 |
| .040" | 3.35" | 72.40# | 68.7# | 141.10 | 0 | 0 | 141.10 | 3.43 |
| .050" | 2.68" | 90.60# | 55.0# | 145.60 | - .67 | - 6.44 | 139.16 | 2.78 |
| .063" | 2.13" | 114.00# | 43.8# | 157.80 | - 1.22 | - 11.70 | 146.10 | 2.25 |
| .071 | 1.89" | 128.50# | 38.8# | 167.30 | - 1.46 | - 14.00 | 153.30 | 2.03 |

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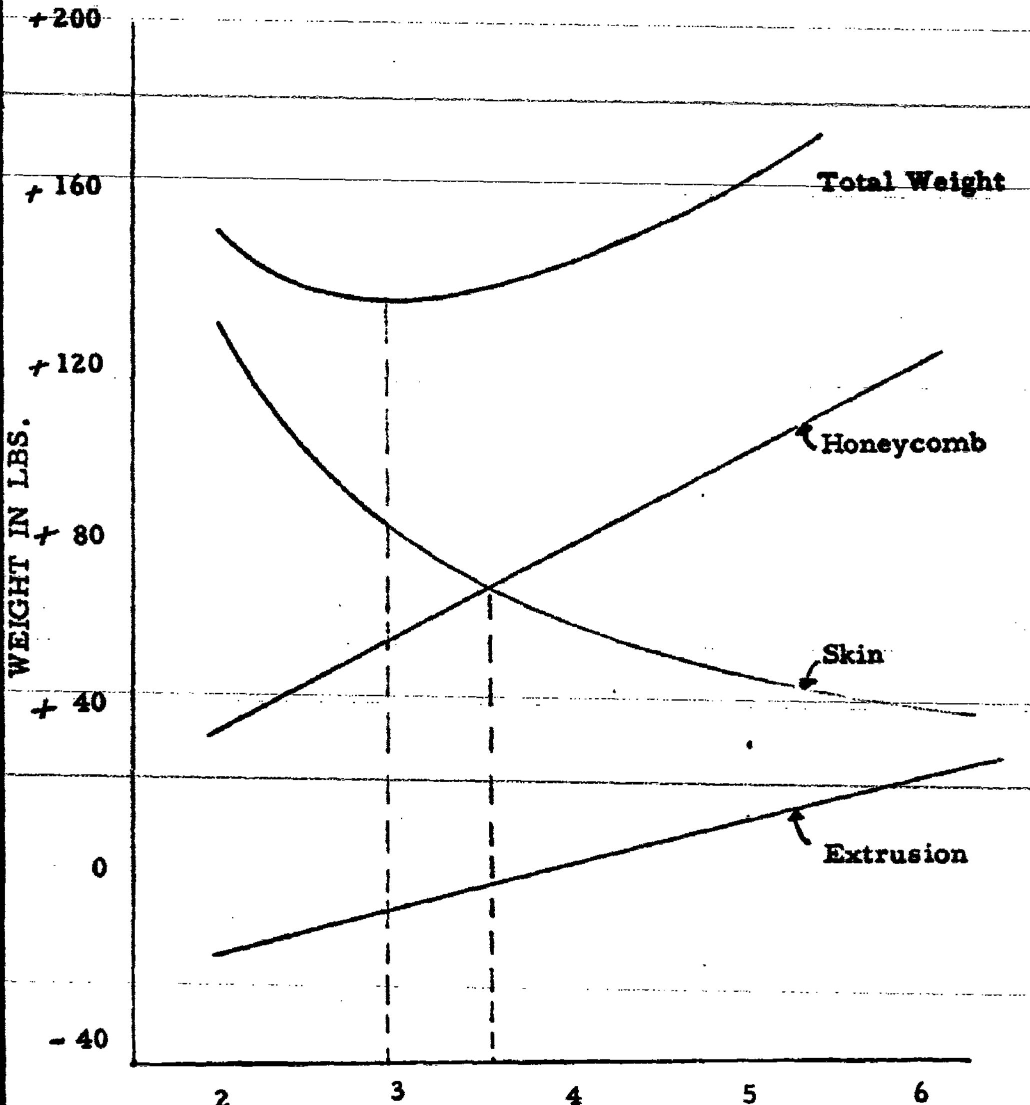
DETERMINATION OF OPTIMUM SANDWICH PANEL THICKNESS




SANDWICH THICKNESS "INCHES"

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REV.______ DATE______

BROOKS & PERKINS
DEFENSE PRODUCTS DIVISION

SHEET______ OF______
SUBJECT______

| Loading Condition | Max. Bending Mom. In Panel In./Lbs. | Skin Stress PSI Top | Skin Stress PSI Bottom | Core Shear lbs/in | Fastening Load Skin to Extru. lbs/In. Edge Mem at corner | Fastening Load Center Long | Fastening Load Joint Horiz. | Edge Member Bending Stress Side PSI | Edge Member Bending Stress Back PSI |
|---|---|---|---|---|---|---|---|---|---|
| 3G. Fwd. | 60,000 | 15,000 | 14,000 | 60 | 700 | 900 | --- | --- | 14,500 |
| 4G. Fwd. | 80,000 | 20,000 | 19,000 | 80 | 900 | 1200 | --- | --- | 20,000 |
| 8G. Fwd. | 160,000 | 40,000 | 38,000 | 160 | 1800 | 2400 | --- | --- | 39,000 |
| 9G. Fwd. | 180,000 | 45,000 | 42,000 | 180 | 2000 | 2700 | --- | --- | 44,000 |
| 2G. Aft | 40,000 | 10,000 | 9,000 | 40 | 450 | 600 | --- | --- | 10,000 |
| Pick Up 4 Corners @2G. | 3,070 In-lbs/In. | 9,750 | 7,800 | 130 | 700 | 750 | 750 | 7900 | 7,900 |

LOADING CONDITIONS AND STRESS LEVELS

88" x 108" 463L PALLET PRESENT TYPE CONSTRUCTION

DYNAMIC LOADING CONDITION .1 SECOND DECELERATION

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TECHNICAL ANALYSIS FORM

BY____ DATE____ CK.____ DATE____ REV.____ DATE____

BROOKS & PERKINS

DEFENSE PRODUCTS DIVISION

SHEET____ OF____ SUBJECT____

| Loading Condition | Max. Bending Mom. in Panel In./Lbs. | Skin Stress PSI Top | Skin Stress PSI Bottom | Core Shear lbs/In. | Fastening Load Skin to Extru. lbs/In. Edge mem at corner | Fastening Load Skin to Extru. lbs/In. Center Long | Fastening Load Skin to Extru. lbs/In. Joint Horiz. | Edge Member Bending Stress Side PSI | Edge Member Bending Stress Back PSI |
|---|---|---|---|---|---|---|---|---|---|
| 3G. Fwd. | 120,000 | 30,000 | 25,000 | 120 | 1200 | 2000 | --- | --- | 27,000 |
| 4G. Fwd. | 160,000 | 40,000 | 33,000 | 160 | 1600 | 2500 | --- | --- | 35,000 |
| 8G. Fwd. | 320,000 | 80,000 | 66,000 | 320 | 3200 | 5000 | --- | --- | 70,000 |
| 9G. Fwd. | 360,000 | 90,000 | 74,000 | 360 | 3600 | 6000 | --- | --- | 81,000 |
| 2G. Aft | 80,000 | 20,000 | 16,000 | 80 | 800 | 1300 | --- | --- | 17,500 |
| Pick Up 4 corners @2G. | 3,070 In-lbs/In. | 9,750 | 7,800 | 130 | 700 | 750 | 750 | 7900 | 7,900 |

108" by 88" platform-static condition

LOADING CONDITIONS AND STRESS LEVELS

88" x 108" 463L PALLET PRESENT TYPE CONSTRUCTION

STATIC LOADING CONDITION

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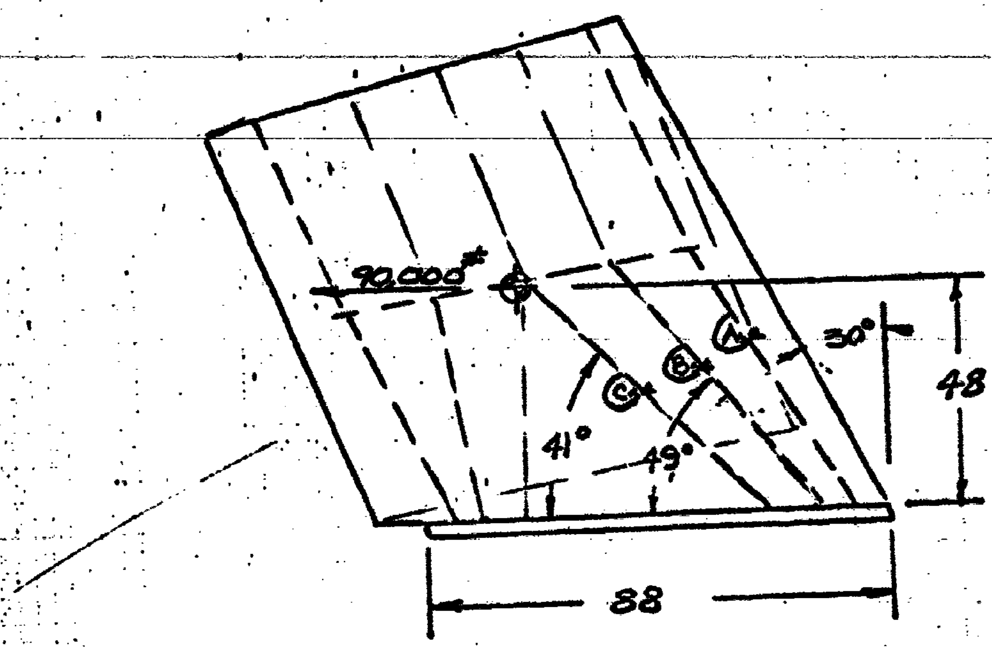
# APPENDIX V

## Determination of Loads in Restraint

## due to

## 9 g Longitudinal Load

DETERMINATION OF LOADS IN RESTRAINT.
DUE TO OVERTURNING MOMENT.



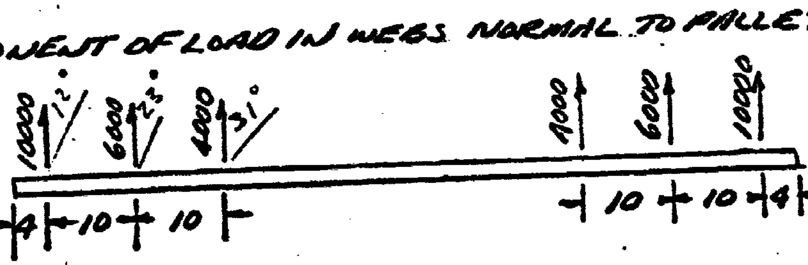

VERTICAL REACTIONS AT PALLET EDGES (FRONT & REAR)

$$\frac{90000 \times 48}{88} = 49{,}000 \text{ LBS.}$$

ASSUME VERTICAL LOADS AT REAR EDGE ARE IMPOSED BY WEBS $A_R$, $B_R$ & $C_R$ AT REAR AND WEB $A_{SR}$ ON SIDE AT REAR. (4 INCH DIFFERENTIAL IS DISREGARDED)

TOTAL IMPOSED VERTICAL COMPONENT = 49,000 LBS.

COMPONENT OF LOAD IN WEBS NORMAL TO PALLET IS LIMITED TO




THIS ALLOWS 60,000 LBS. RESTRAINT TO OVERCOME OVERTURNING MOMENT AS COMPARED TO 49,000 LBS. REQ'D

LOADS IMPOSED BY 96 STATIC LOAD = $\frac{49}{60}$ × ALLOWABLE

= .815 WEB ALLOWABLE

$A_{SR}$ = .815 × 10,000 = 8,150 LB.

$A_R$ = .815 × 10,000 = 8,150 LB.

$B_R$ = .815 × 6,000 = 4,900 LB.

$C_R$ = .815 × 4,000 = 3,260 LB.

LOADS IN PLANE OF WEBS AT REAR

$A_{SR} = \frac{8,150}{\cos 30°} = 9,400$ LB.

$A_R = \frac{8150}{\cos 30°} = 9,400$ LB.

$B_R = \frac{4900}{\cos 30°} = 5,650$ LB.

$C_R = \frac{3260}{\cos 30°} = 3,760$ LB.

DETERMINATION OF LOADS IN RESTRAINT
DUE TO LONGITUDINAL FORCES.

WEB MEMBERS CAPABLE OF RESTRAINT ARE.

AT REAR. – $A_R$, $B_R$, $C_R$

AT SIDE. – $A_{SR}$, $B_{SR}$, $C_{SR}$

AT FRONT. – $A_f$, $B_f$, $C_f$

AT EACH LOCATION 2 EACH OF THESE WEBS ARE EFFECTIVE.

LOAD DISTRIBUTION THEN BECOMES

$A_{SR}, A_R, A_f = 1.0$

$B_{SR}, B_R, B_f = .6$

$C_{SR}, C_R, C_f = .4$

TOTAL LONGITUDINAL COMPONENT

$A_{SR} = 1.0 \times \text{TAN } 30° \times 2 = 1.15$

$A_R = 1.0 \times \text{TAN } 30 \times 2 = 1.15$

$A_f = 1.0 \times 2 = 2.00$

$B_{SR} = .6 \times \text{TAN } 41° \times 2 = 1.03$

$B_R = .6 \times \text{TAN } 30° \times 2 = .69$

$B_f = .6 \times 2 = 1.20$

$C_{SR} = .4 \times \text{TAN } 49° \times 2 = .92$

$C_R = .4 \times \text{TAN } 30° \times 2 = .46$

$C_f = .4 \times 2 = .80$

TOTAL LONGITUDINAL COMPONENT = 9.40 = 90,000 LBS.

LOADS IN PLANE OF WEBS

$A_{SR}, A_R, A_f = \frac{1.0 \times 90{,}000}{9.4} = 9600$ LBS.

$B_{SR}, B_R, B_f = \frac{.6 \times 90{,}000}{9.4} = 5{,}750$ LBS.

$C_{SR}, C_R, C_f = \frac{.4 \times 90{,}000}{9.4} = 3{,}840$ LBS.

THESE LOADS ARE SLIGHTLY HIGHER THAN THOSE REQUIRED TO OVERCOME THE OVERTURNING MOMENT AND WILL BE USED FOR DESIGN.

LOADS IN WEBS OF REAR PANEL

$$A_R, A_{3R} = \frac{9600}{\cos 12^\circ} = 9830 \text{ LB.}$$

$$B_R, B_{3R} = \frac{5750}{\cos 23^\circ} = 6250 \text{ LB.}$$

$$C_R = C_{3R} = \frac{3240}{\cos 31^\circ} = 4500 \text{ LB.}$$

IF 8% MORE STRENGTH IS REQ'D FOR PREVENTION OF LIGHT DEGRADATION, THIS SHOULD BE COMBINED WITH A JOINT EFFICIENCY OF 85% - TOTAL FACTOR IS THEN

$$\frac{1.08}{.85} = 1.27$$

$$A = 9830 \times 1.27 = 12{,}500 \text{ LBS.}$$

$$B = 6250 \times 1.27 = 7{,}950 \text{ LBS.}$$

$$C = 4500 \times 1.27 = 5{,}720 \text{ LBS.}$$

# APPENDIX VI

## EXCERPTS FROM APGC-TR-64-61
## EVALUATION OF C-130 AIRCRAFT
## LOW ALTITUDE PARACHUTE
## EXTRACTION SYSTEM

The extraction factor for a given load was determined by dividing the parachute drag force for the airspeed flown by the total load weight, including the pallet. The extraction factor proved to be useful for determining the optimum airspeed, load, and parachute combination. Results indicated that an extraction factor of approximately 1.0 to 2.0 was satisfactory. At an appreciably low extraction factor, the extraction zone size was increased because of longer slide distances. At an appreciably higher extraction factor, the pallet impact angle was more difficult to control.

As the center of gravity of the load passed over the end of the aircraft ramp, the unbalanced vertical support caused the load to tip (gravitational tip off). The slower the load velocity with respect to the aircraft at extraction, the more the load tipped. It was evident that the load was given a rotational velocity due to this gravitational tip off.

If the extraction line was attached so that the drag force was exerted at the center of gravity, the load continued to rotate unrestricted. It was concluded that if the point at which this drag force was exerted was moved some distance aft and above the center of gravity, a moment would result to counteract this rotation. The counter-action of this rotation was then attempted experimentally to determine the optimum point of the extraction line attachment with respect to the load center of gravity.

All extractions made in this test, using modified pallets, were successful when the pallet impact angle was greater than minus $7^{\circ}$ and less than $38^{\circ}$. Considering the range of the pallet impact angles for successful extractions made using the modified pallet, it appears that a constant rigging angle of $12^{\circ}$ can be used. With this rigging angle, one can be at least 90 percent confident that the pallet will impact within the range of successful extractions as determined in this test.

At release a deceleration of -1 to -3g was observed in the longitudinal plane until impact. A vertical force of approximately + 12 to + 18g was experienced as the tail of the pallet touched down and the nose rotated and impacted. At nose impact, a short duration longitudinal deceleration of -20 to -30g accompanied by a + 10 to + 15g vertical force was encountered. Short duration longitudinal and vertical forces of -5 to + 7g were evidenced as the pallet slid over the unimproved terrain until pallet rest.

The pallet used for the durability evaluation was the standard 463L modular pallet. This pallet is an expendable item not designed to be reused. To facilitate the most economical gathering of data to satisfy other test objectives and to serve as a basis for comparison, several pallets were modified to enable them to be reused. Considerable effort was expended to gain success with the standard pallet; however, of 23 extractions made with it, only 7 were successful. Most of the failures occurred because the pallet dug in the ground on impact. Several drops were made at excellent impact angles, but in the 4000-lb. and 5000-lb. load range the pallet failed structurally.

Loads were extracted at ramp altitudes varying from 14.2 ft. to 3.4 ft. Results indicated that the aircraft should be as low as possible at the time the load is extracted. This would minimize the time interval from load separation to impact. This was proven to be very critical. At this time interval was lengthened, the effects of any errors in accurately locating the point of attaching the extraction line were more pronounced. If attached too low, the pallet motion was arrested and reversed, causing the pallet to impact nose down. If attached too high, the rotation had time to continue, resulting in an excessively nose-high impact angle.

# APPENDIX VII

## COST AND WEIGHT COMPARISONS

## OF

## VARIOUS PALLET AND PLATFORM SYSTEMS

## TABLE IX

### 88" x 108" LOGISTICS PALLET WEIGHT BREAKDOWN

| | Present 463L | 4 Modules 44"x54" | 2 Modules 54"x88", 44"x108" | (Module 88" x 108" Separate Restraint Extrusion | Integral Extrusion Two Sides | Recommended 88"x108" Logistic Pallet Reduced Weight & Improved |
|---|---|---|---|---|---|---|
| Facings: .080 7075-T6 | 123 | 106 | 110 | 116 | 118 | |
| .063 6061-T6 | | | | | | |
| .063 7075-T6 | | | | | | 112 |
| Core: Balsa 8# Average Density: | 85 | 72 | 75 | 80 | 81 | |
| Paper Honeycomb: 4.0#/Cu. Ft. Density: | | | | | | 42 |
| Adhesive: | 10 | 10 | 10 | 10 | 10 | 10 |
| Extrusion Panel & Integral Vertical Restraint: | 60 | 118 | 91 | 52 | 60 | 60 |
| Add on Restraint Rails: | -- | 77 | 77 | 80 | 44 | -- |
| Miscellaneous Hardware Corner brackets & pins: | 13 | 28 | 22 | 19 | 17 | 16 |
| TOTAL: | 291 | 411 | 385 | 357 | 330 | 240 |

## TABLE X

### COST AND WEIGHT COMPARISONS OF 88" x 108" LOGISTICS PALLETS OF VARIOUS CONFIGURATIONS

| PALLET CONFIGURATION | WEIGHT TOTAL | #/SQ FT. | COST TOTAL | $/SQ FT. |
|---|---|---|---|---|
| 1. Present 463L Pallet | 291 | 4.4 | 250 | 3.80 |
| 2. One size module 54" x 44" 4 required - separate restraint lip required 4 sides | 411 | 6.20 | 316 | 4.8 |
| 3. One size module 54" x 88", 2 required. 44" x 108", 2 required. Separate restraint lip required - 4 sides | 285 | 5.7 | 307 | 4.65 |
| 4. One size module 88" x 108" separate restraint lip required - 4 sides | 357 | 5.4 | 281 | 4.25 |
| 5. One size module 88" x 108" integral restraint lip - two short sides and separate restraint lip - 108" sides | | | | |
| A. 463L type rail: | 347 | 5.3 | 278 | 4.16 |
| B. Air-drop type rail: | 330 | 5.0 | 271 | 4.06 |
| 6. Recommended 88" x 108" logistic pallet .060 7075-T6 facings and paper honeycomb core | 240 | 3.3 | 223 | 3.4 |

## TABLE XI

## COST AND WEIGHT COMPARISONS OF AIR-DROP PLATFORM CONFIGURATIONS

| | Platform Configuration | Approximate/Wt. Lin. Ft. | Approximate/ Cost/Lin. Ft. |
|---|---|---|---|
| 1. | Present Modular Platform | 43# | $30.4 |
| 2. | One size module 44" x 108" (Separate side rails) | 56# | $42 |
| 3. | Two module sizes 88" x 108 + 48" add on modules (Separate side rails) | 53# | $38 |
| 4. | Two module sizes 88" x 108" + 50" add on modules Integral side rail (Non-reversible) | | |
| | A. Air drop rail configuration: | 46# | $36 |
| | B. 463L type rail configuration with bolt on bar for airdrop type of tie-down ring: | 47# | $37 |
| 5. | One module size 50" x 108" with integral restraint lip member Bushings to take tie-down rings | 48# | $38 |
| 6. | Recommended: One size module 50" x 108", same as 5 above, except: .060 7075-T6 facings paper honeycomb core: | 37# | $34 |

TECHNICAL ANALYSIS FORM

| BY ______ DATE ______ | BROOKS & PERKINS | SHEET ______ OF ______ |
|---|---|---|
| CK. ______ DATE ______ | b+p | SUBJECT ______ |
| REV. ______ DATE ______ | DEFENSE PRODUCTS DIVISION | |

## COST AND WEIGHT COMPARISONS OF 88" x 108" LOGISTICS PALLET

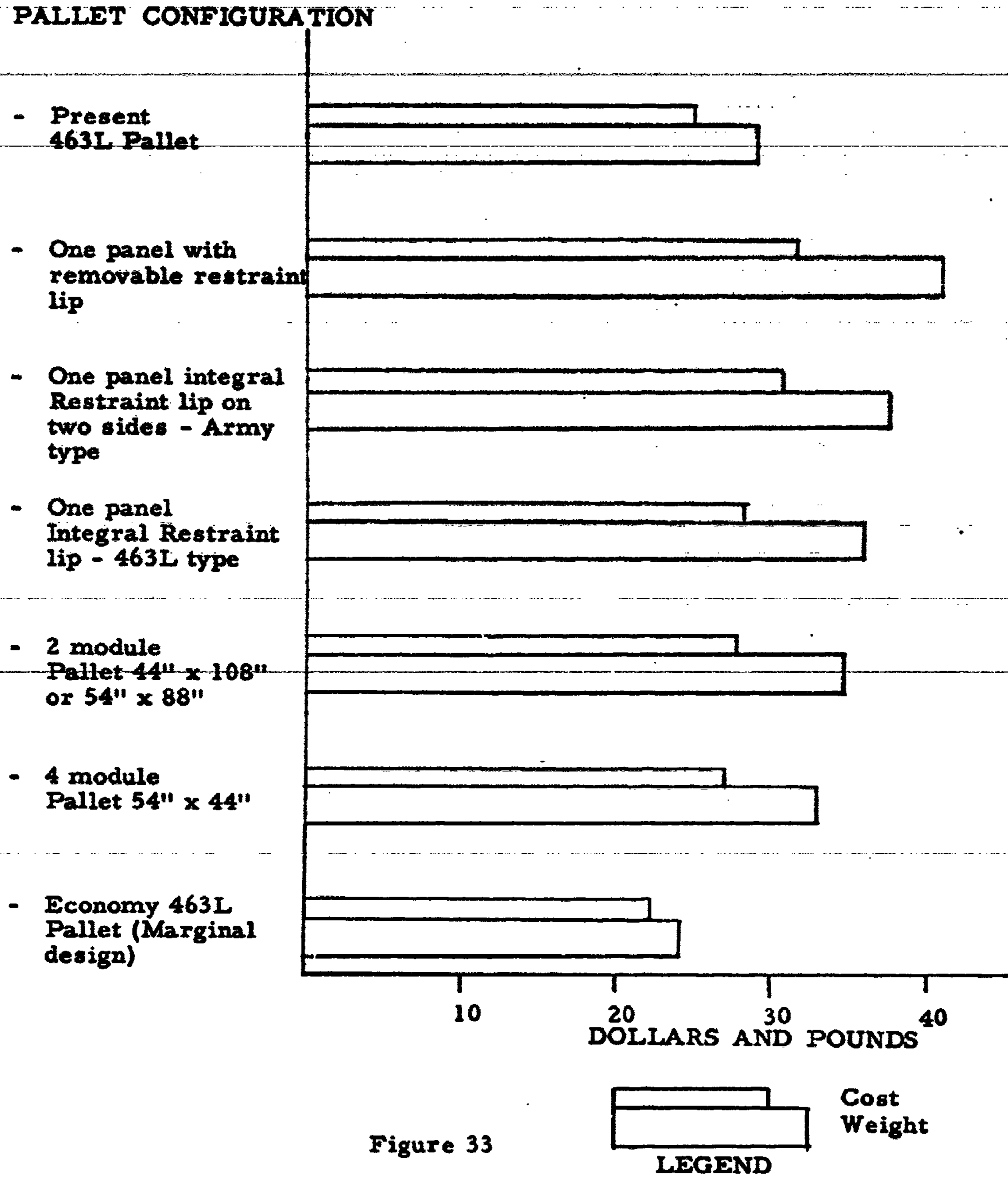



Figure 33



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## COST AND WEIGHT COMPARISONS
## AIRDROP PLATFORM SYSTEMS

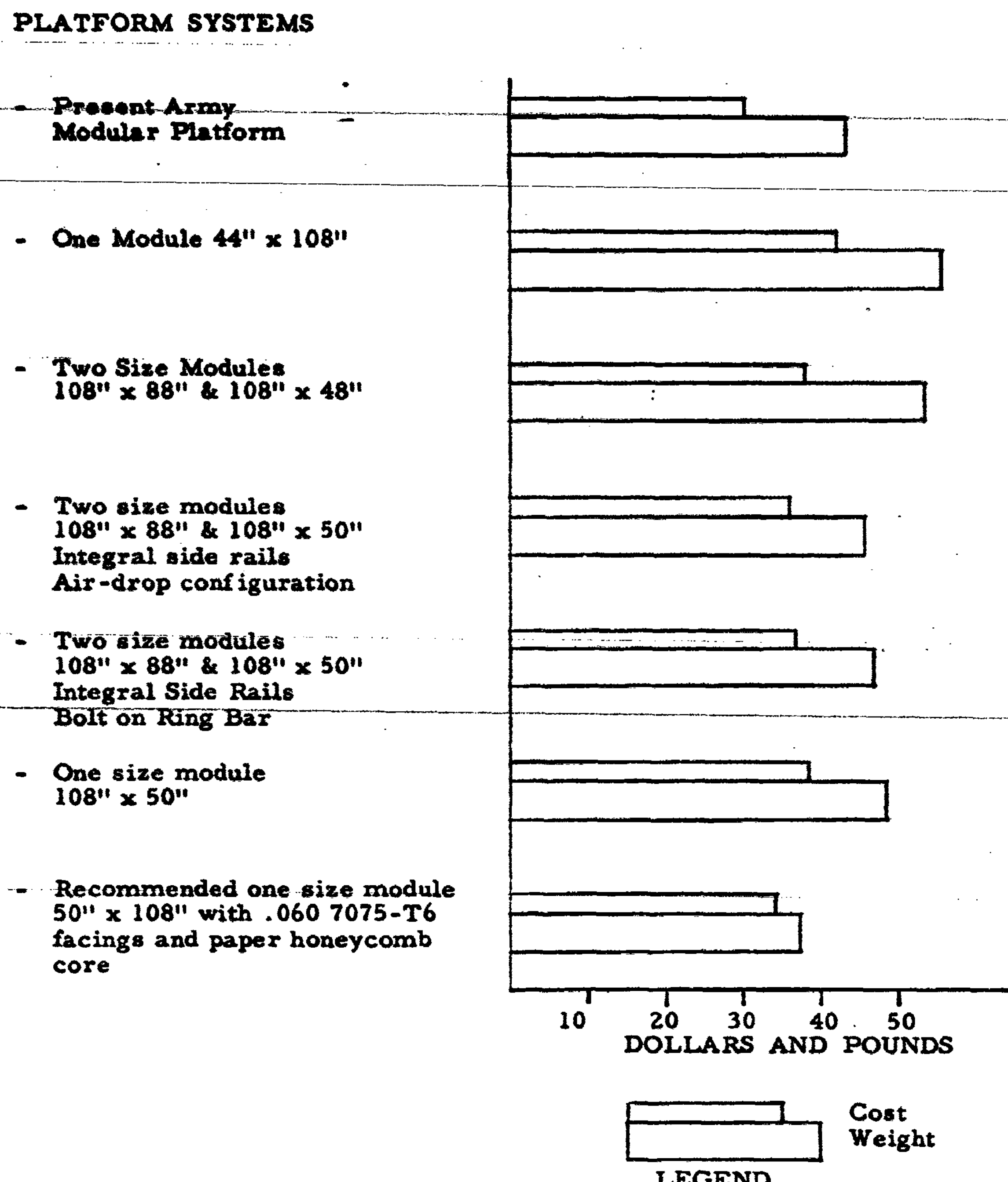


Figure 34



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# APPENDIX VIII

## OPTIONAL JOINT DESIGNS INVESTIGATED

TECHNICAL ANALYSIS FORM

BY H.R.GRIST DATE 6-28-65 | BROOKS & PERKINS b+p DEFENSE PRODUCTS DIVISION | SHEET ____ OF ____
CK. ______ DATE ______ | SUBJECT ______
REV. ______ DATE ______

## OPTIONAL EXTRUSIONS DESIGN

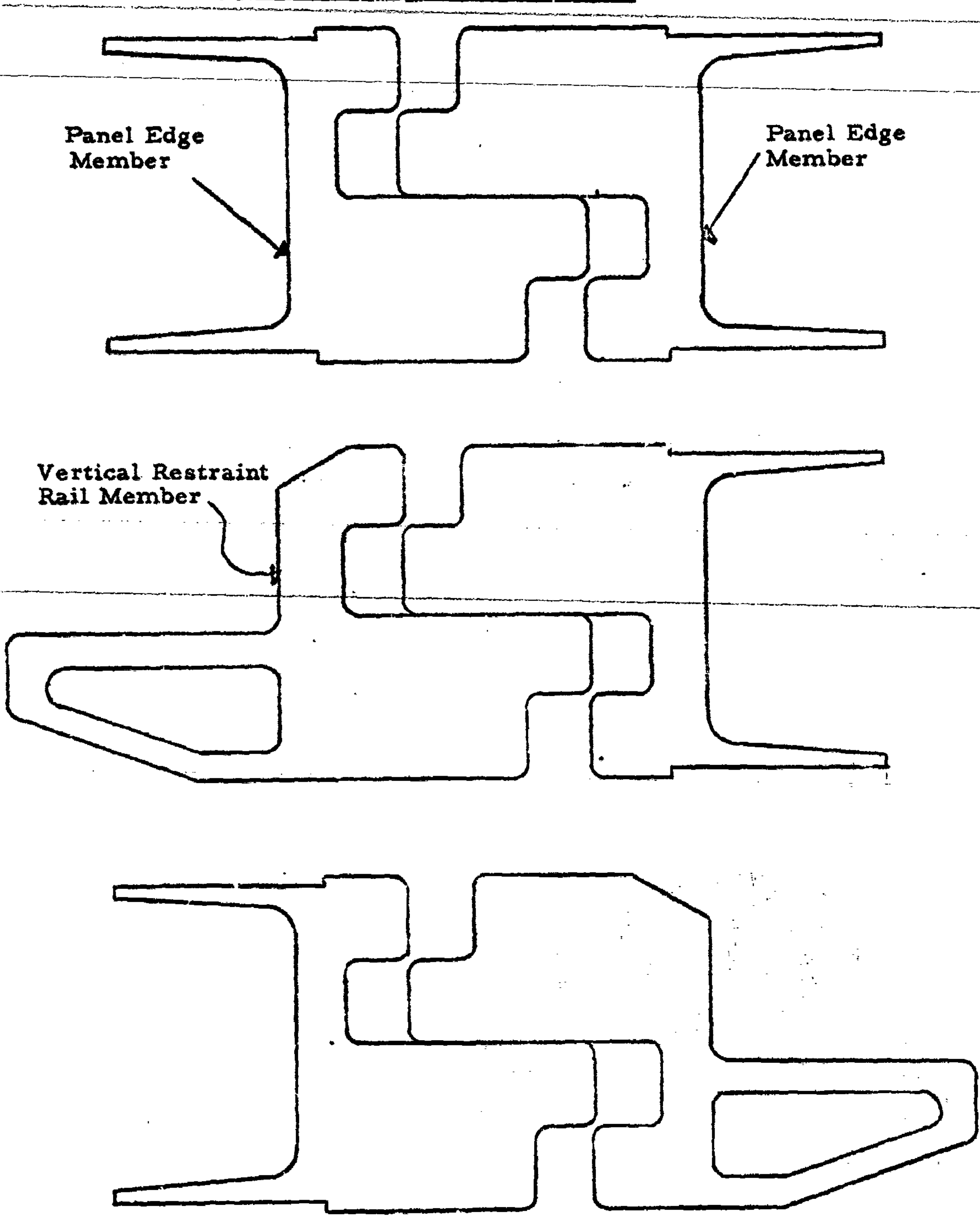


Figure 35

TECHNICAL ANALYSIS FORM

| BY H.R. SPRISTI DATE 6-28-? | BROOKS & PERKINS<br>b+p<br>DEFENSE PRODUCTS DIVISION | SHEET ____ OF ____ |
|---|---|---|
| CK. ______ DATE ______ | | SUBJECT ______ |
| REV. ______ DATE ______ | | |

## OPTIONAL EXTRUSIONS DESIGN

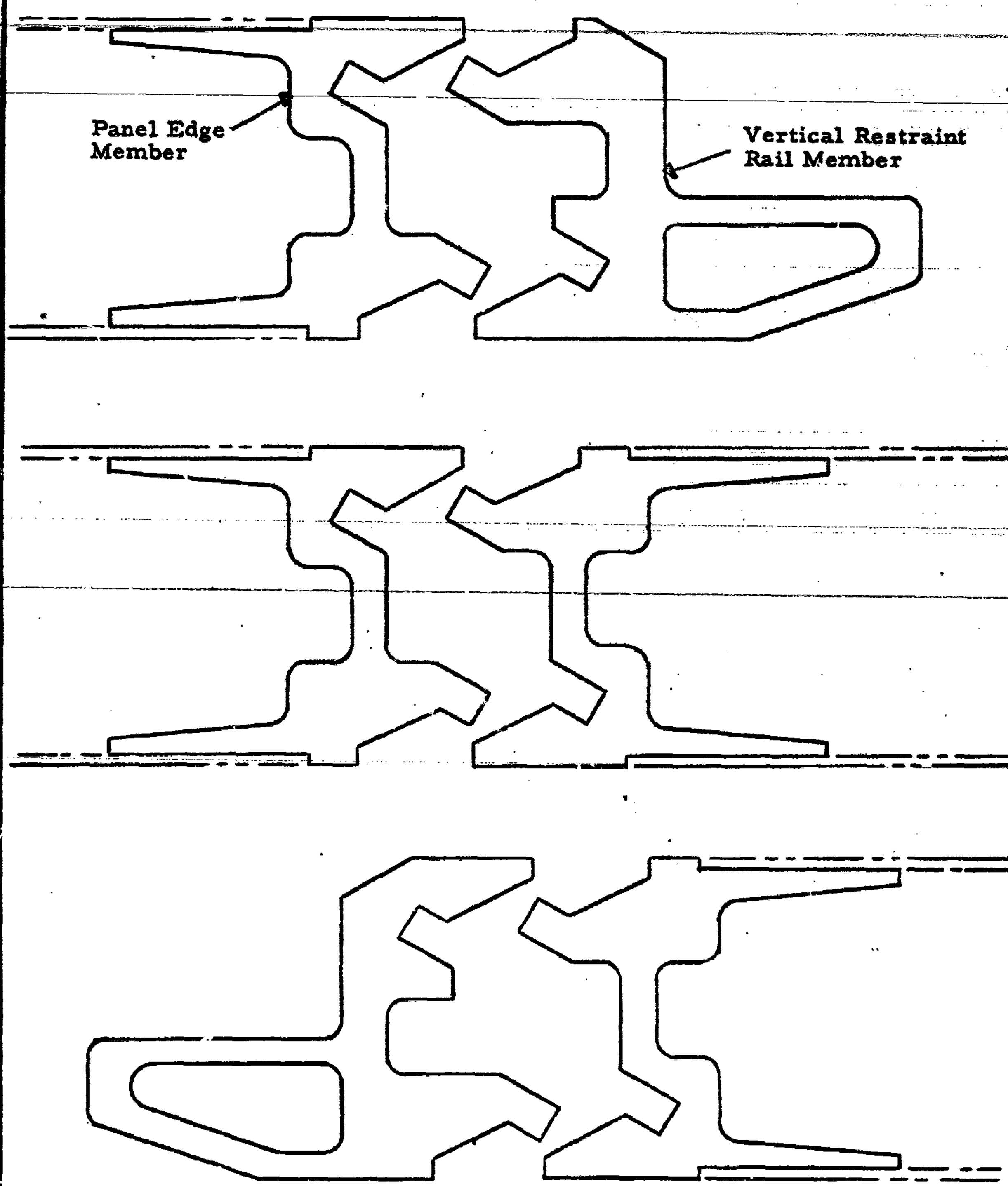


Figure 35a

# APPENDIX IX

## CONNECTING MEMBER JOINT TEST

**TEST:** Joint Test

**PURPOSE:** To compare the strength of the joint and of the sandwich panel construction.

**EQUIPMENT & APPARATUS:**
(1) Dake Hydraulic Press
(2) Dial Test Indicator
(3) Sample as shown in Figure 1

**PROCEDURE:** The sample and dial indicator are positioned in the press as shown in Figure 2.

A steel I - Beam was placed in the center of the sample, to distribute the load. A slight pre-load was put on the beam; the indicator was set to zero.

Load readings were made at 50 PSI intervals. The load was increased in this manner until failure occured.

**RESULTS:** The loads and deflections of the sample are tabulated below. The sample failed in the sandwich construction due to core shear failure. A slight yielding of the material in bearing was visible around the pins in the bottom of the joint.

**RECOMMENDATIONS:** The results of this test indicate that the joint material 6061-T6 should be replaced with 6070-T6.

| GAUGE PRESS | *LOAD LBS. | DEFL. IN INCHES |
|---|---|---|
| 150 | 4240 | .139 |
| 200 | 5660 | .195 |
| 250 | 7070 | .250 |
| 300 | 8480 | .320 |
| 350 | 9900 | .390 |
| 400 | 11350 | Core Failure |

* One PSI gauge = 28.27 lbs. pressure on the ram.

TECHNICAL ANALYSIS FORM

| | | |
|---|---|---|
| BY E.MAGEE DATE 6-25-66 | BROOKS & PERKINS | SHEET OF |
| CK. DATE | b+p | SUBJECT |
| REV. DATE | DEFENSE PRODUCTS DIVISION | |

'TEST SAMPLE'

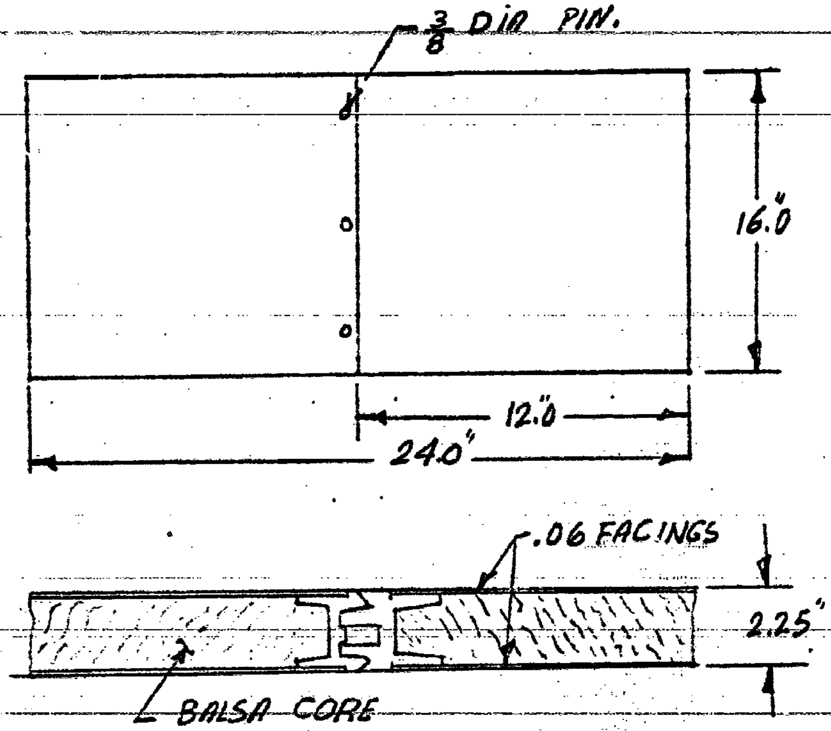


FIG. '1'



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TECHNICAL ANALYSIS FORM

| BY E. DREED DATE 6-22-61 | BROOKS & PERKINS | SHEET ___ OF ___ |
|---|---|---|
| CK.______ DATE______ | b+p | SUBJECT______ |
| REV.______ DATE______ | DEFENSE PRODUCTS DIVISION | |

TEST SET UP.

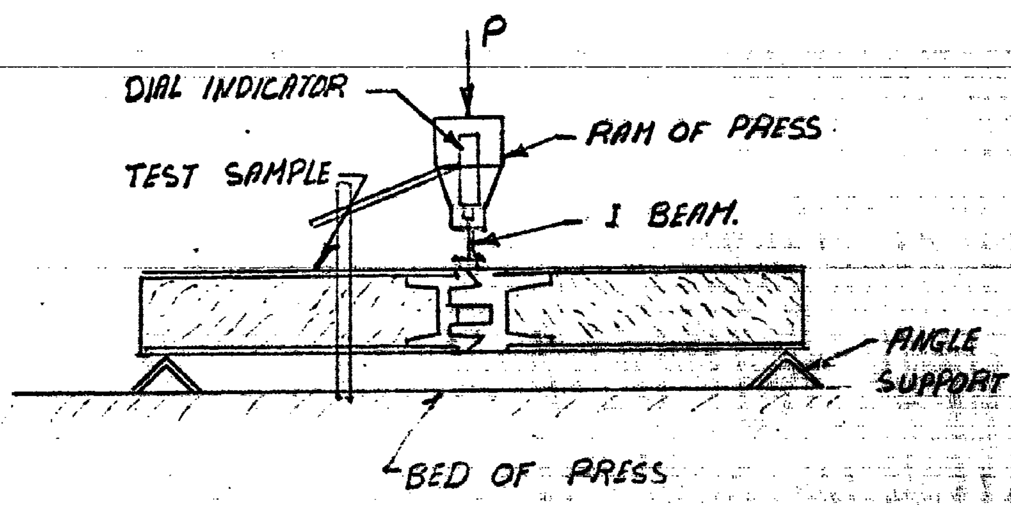


FIG '2'



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# APPENDIX X

## U. S. STEEL BONDED SANDWICH PANEL AND PROPOSED "AIR DECK" TYPE OF SANDWICH CONSTRUCTION FOR LOGISTICS PALLET AND AIR DROP PLATFORM

## U.S. STEEL PROPOSED "AIR DECK" UNIVERSAL PLATFORM

The U.S. Steel Company was contacted to determine what materials or construction designs they might have that would be applicable to the Universal Platform program. They said they were very interested and had a sandwich panel construction called "Air-Dek" which they would propose for the platform construction. Several meetings were arranged in which all of the problems were discussed. As a result, U.S. Steel Company prepared drawings of their proposed all steel design for both the logistics pallet and the air-drop platform utilizing their "Air-Dek" construction.

### U. S. Steel Air-Dek logistics pallet description

Figure 36 shows the proposed design of the logistics pallet. The panel construction consists entirely of bonded steel core and facings. The core is made up of a series of individual pieces assembled in a square pattern similar to egg-crating as shown in the cut-away section, Figure 36. The pieces of core are formed into a small channel section and are notched and slit half way through the section at each point that they intersect. After the core is assembled all adjacent edges and corners are coated with an adhesive. The facings are applied to both surfaces and the entire assembly placed in the curing oven. The vertical restraint lip is obtained by extending the top and bottom facings and forming them around short stiffening ribs that are fastened to the ends of core members. See sectional view. The cargo tie-down rings brackets are bolted to the top of the pallet. Threaded aluminum inserts are secured in the core to take these bolts. See Section A-A.

A logistics pallet so constructed would be very rugged and should have a long useful life. The estimated weight is slightly higher than the present 463L pallet. It is difficult to obtain a realistic production cost, however, as there are no production facilities set up to manufacture this type of structure as of yet.

### U.S. Steel "Air-Dek" Air-drop Platform Description

Figure 37 shows the proposed design of an air-drop platform constructed of steel. This platform consists of 50" x 108" modules with integral vertical restraint lips. The panel construction is similar to that described above for the logistics pallet. The modules are held together by means of splicing plates bolted through the tongue shaped edges of the panels. See Section B-B. The tie-down rings are fastened to the platform in the same manner as on the logistics pallet.

This air-drop platform would have very good structural properties especially for torsion and bending. Because of the exceptional ruggedness of the construction this "Air-Dek" air-drop platform is recommended for a reuseable training type of platform.

From the table on Page X4 it can be seen that the estimated weight per square foot for a training platform is 14.9 lbs as compared to about 5.8 lbs per square foot for the present modular air-drop platform.

The following is a list of advantages which will occur to the Government through the use of the U.S. Steel Air-Dek Concept.

1. Design flexibility to resist practically any combination of loadings by varying pallet thickness, cell spacing of the core, thickness of core material and cover sheets, and the material of construction. By way of illustration, a training pallet to sustain numerous drops could be designed by varying the above features and still be compatible with the 463L system. An operational pallet for limited drops could also be designed at lower cost then the training pallet and with a large weight savings. The attached tabulation compares various features of the training pallet with the operational pallet.

2. The USS Air-Dek structure is orthotropic in that it has equal structural properties in both directions in the plane of the pallet. The attached graph shows results of the experimental tests of bending rigidity of several types of USS Air-Dek. This data applies to both directions of the pallet structure, and this bi-directional load carrying capacity accounts for the high rigidity of the structure at lower unit weights.

3. Resistance to puncture loads more than satisfy Air Force requirements.

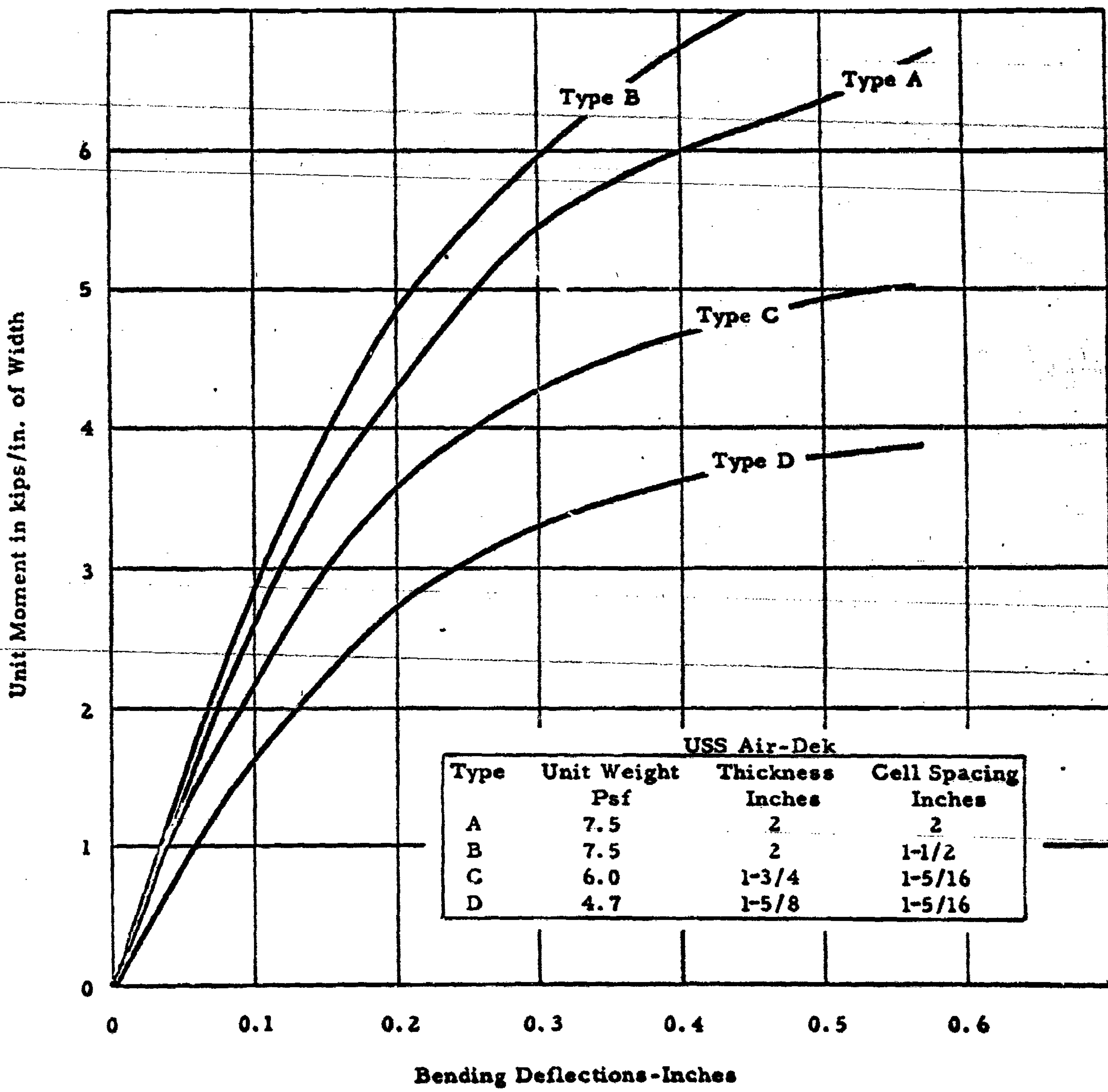
4. Use of steel in this concept utilizes non-critical material.

5. Ease of fabrication does not limit sources of supply and results in a larger mobility base.

6. USS Air-Dek pallets can be fabricated economically for performance requirements.

## Comparison of Operational and Training Pallets

| | Operational Pallet | Training Pallet |
|---|---|---|
| Unit Weight, Basic Section, psf | 4.5 | 12.7 |
| Unit Weight, Overall, psf | 5.2 | 14.9 |
| Yield Moment, in.k./ft. width | 36.4 | 348.0 |
| Shear Capacity, k./ft. width | 9.1 | 30.0 |
| Crushing Strength, psi | 500.0 | 800.0 |
| Bending Stiffness EI, k.in.$^2$/ft. width | 11,800 | 348,000 |




USS Air-Dek

| Type | Unit Weight Psf | Thickness Inches | Cell Spacing Inches |
|---|---|---|---|
| A | 7.5 | 2 | 2 |
| B | 7.5 | 2 | 1-1/2 |
| C | 6.0 | 1-3/4 | 1-5/16 |
| D | 4.7 | 1-5/8 | 1-5/16 |

USS AIR-DEK - TYPE D

Thick - 1-5/8 in.
Unit Weight - 4.7 psf
Cell Spacing - 1-5/16 in.
Material Thickness - 24/25/25 gage

Puncture Test - 750 pounds on 1.0 sq. in.

| Deflection of mat when load on intersection of core pieces | | | | Deflection of mat when load on center of cell spacing | | | |
|---|---|---|---|---|---|---|---|
| Square Test | | Round Test | | Square Test | | Round Test | |
| Stainless Steel | Cor-Ten | Stainless Steel | Cor-Ten | Stainless Steel | Cor-Ten | Stainless Steel | Cor-Ten |
| .0235 | .0190 | .0215 | .0170 | .0245 | .0204 | .0210 | .0250 |

No (0.0) measurable permanent deflection after load removal.

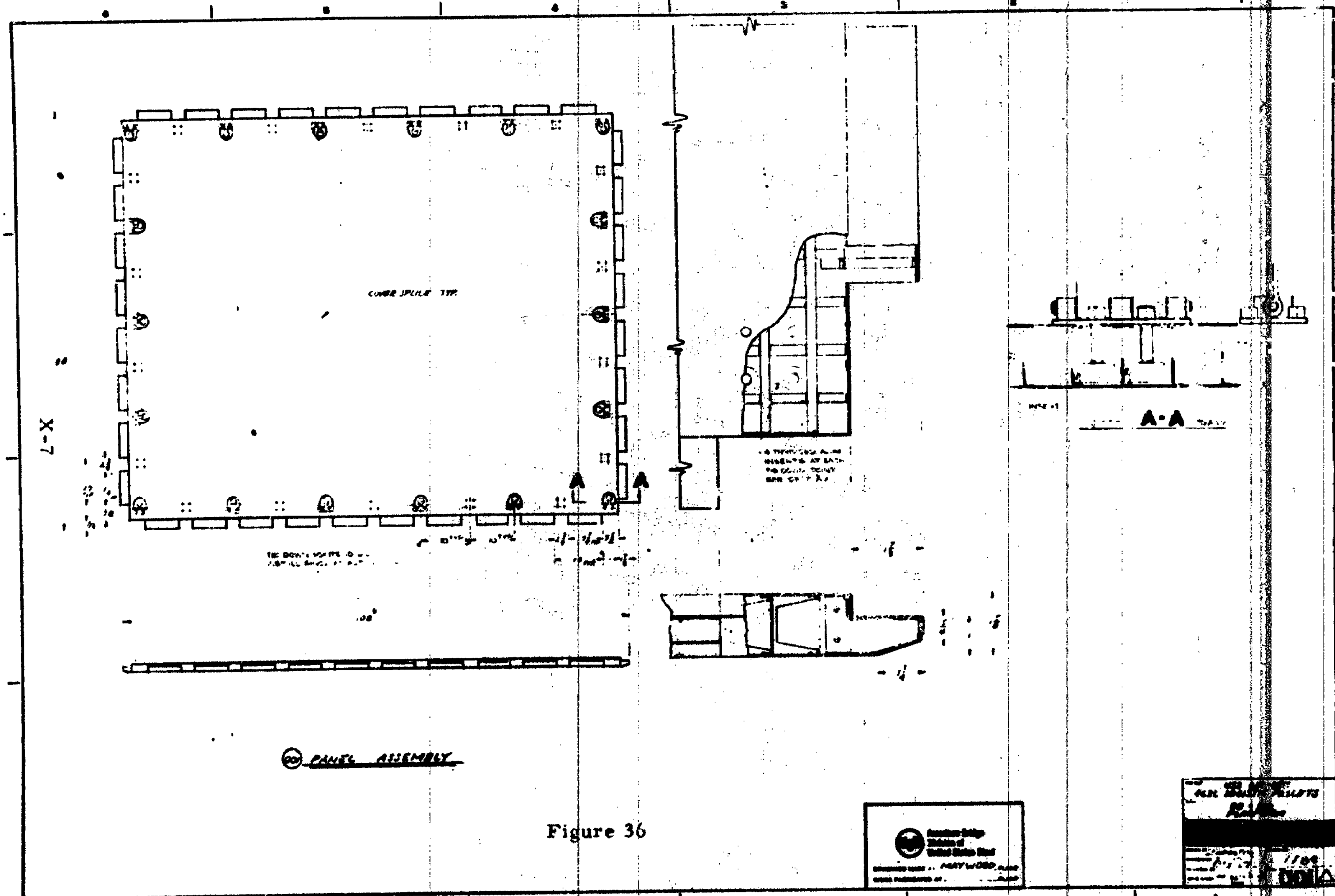
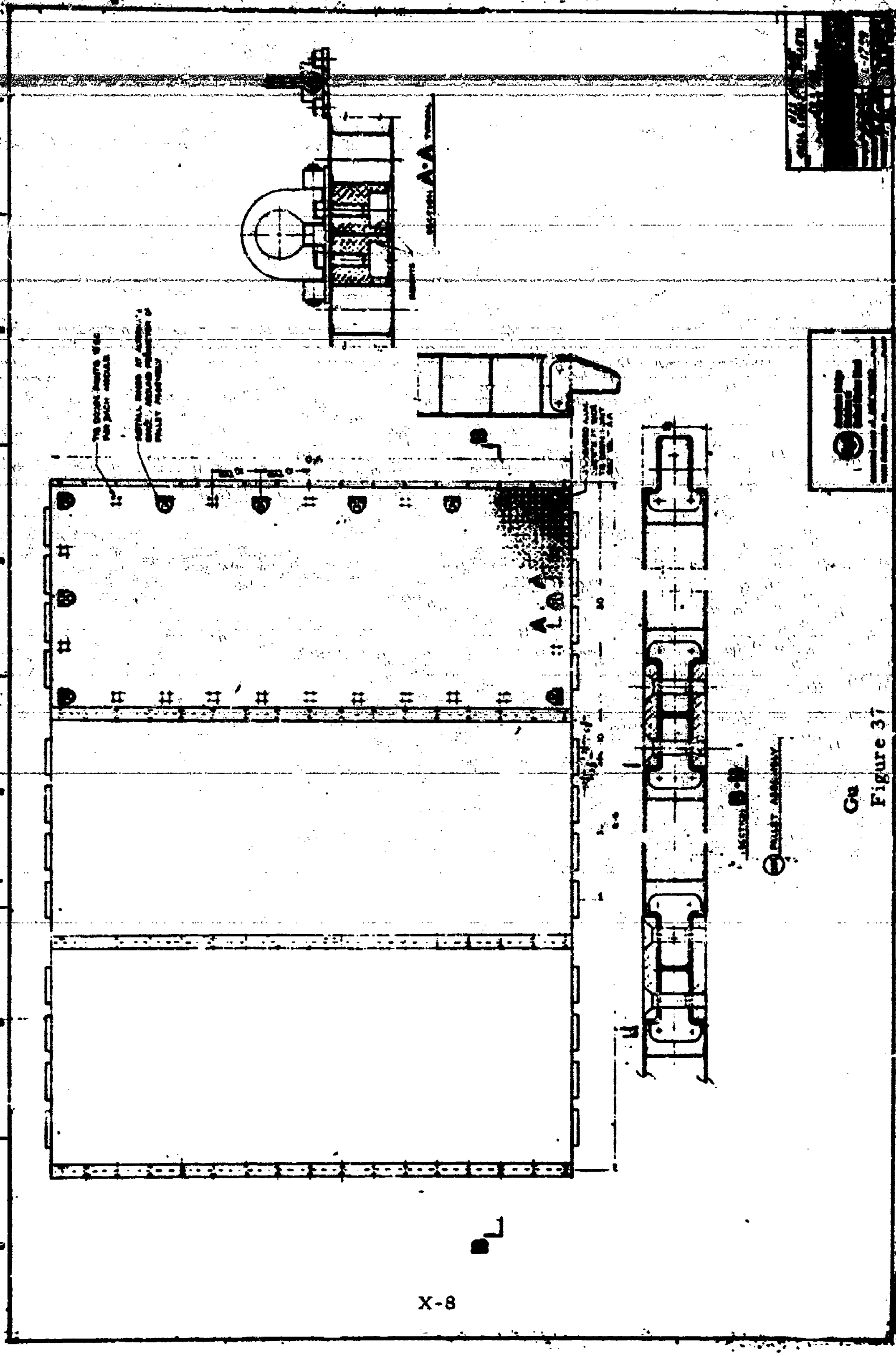



Figure 36



Ga
Figure 37

# United States Steel Corporation

## Bonded Steel Sandwich Panel

The Bonded Steel Sandwich Panel consists of an integral formed steel core assembly with a flat skin or facing bonded to each side of the core.

The core assembly is similar to honeycomb construction in that it consists of adjoining hexagonal shaped cells. The hex is formed by joining two corrugated strips. The corrugated strips are flanged or in cross-section are channel shaped. The flange is discontinuous and is separated at the corner of the corrugation. The flanges are used as bend-over tabs in the areas where the corrugated strips mate together. These flanges, when crimped, hold adjoining corrugated strips together. The flanges that are not bent over are used as surface area for attaching the skins.

In production, the individual core pieces would be fabricated on roll forming equipment which would blank and form the corrugated shape in a continuous operation from coil stock. The core pieces would be chemically cleaned in a dip bath operation and transferred to a special assembly machine. The special machine would coat the pieces with adhesive in the selected areas where adjacent strips mate together and then crimp the locking tabs. A core section of desired size would be produced and transferred to another machine which would coat the core flange areas with adhesive. The prepared core would then be ready for attaching the skins.

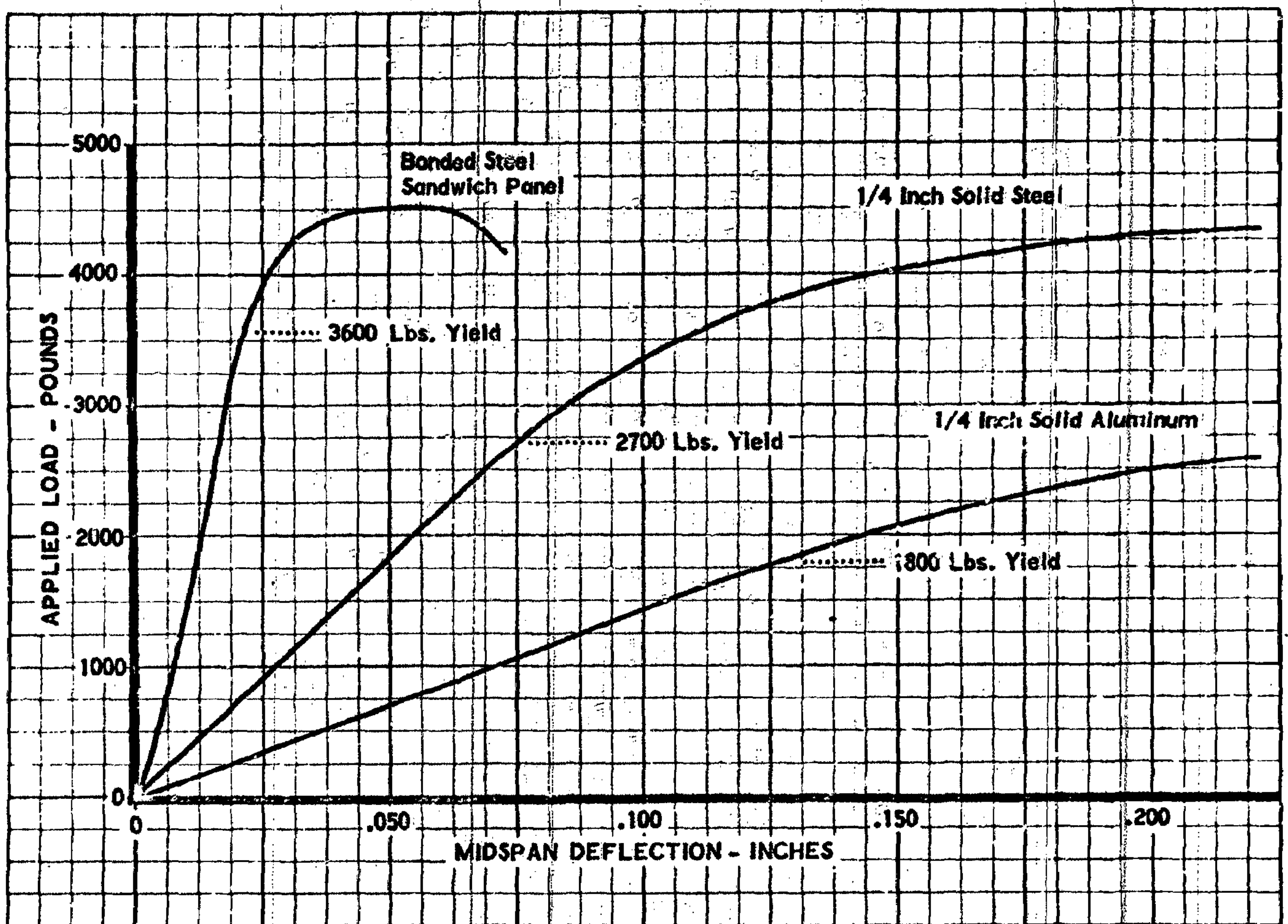
The adhesive used in assembling prototype panels was a thermal setting epoxy (3M type EC-2186) with a sixty minute cure at 350°F. Chemical cleaning of the core pieces and skins was done with a conventional steel degreasing solution. The steel used for both core and skins was AISI 1010, No. 3 temper. Material thickness is .010 inch for the core pieces and .025 inch for the skins. Overall panel thickness is one inch with a .005 inch nominal bond line thickness.

The size of the hex cell in the core is determined by the shape of the corrugated strip. For a particular set of roll forming equipment and assembly fixtures, only one core configuration can be produced. The size of the cell that has been evaluated on a prototype basis is a hex with a side length of 3/8 inch.

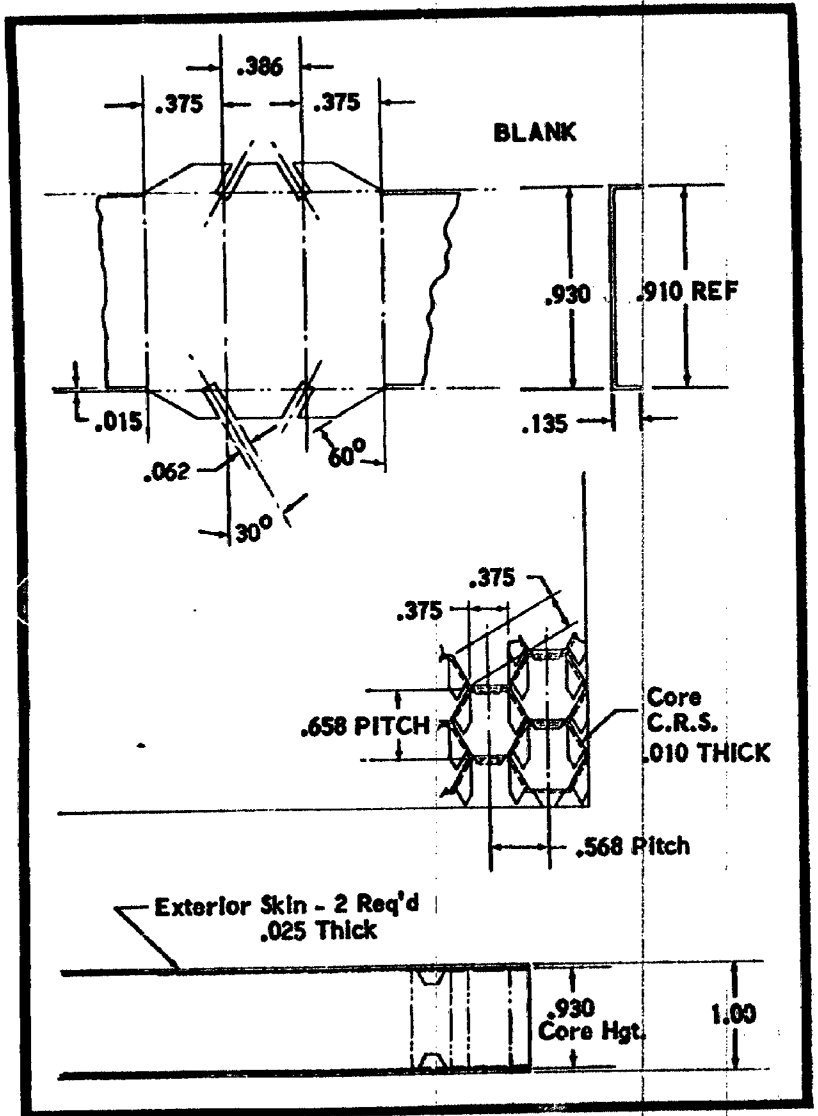
This core configuration is well suited for high volume production of large panels. The only size limitation would be the width of the assembly assuming a curing oven could be constructed to handle any size. No pressure is required during the cure cycle thus simplifying assembly. Dimensional tolerances are not critical and convention roll forming tolerances are adequate for assembly of the core.

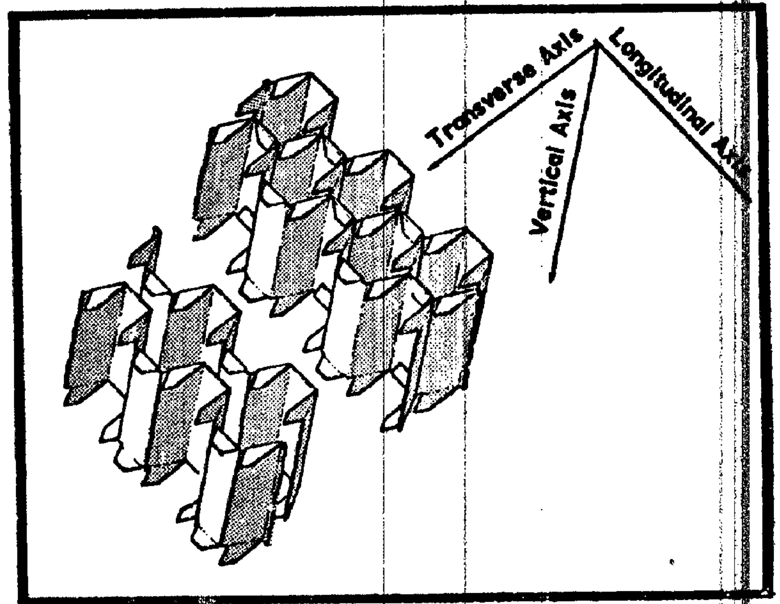
The strength of the panel assembly is very good and its strength to weight ratio is very high. In this configuration the shear strength of the core is approximately coincidental with the bond strength of the skin to core attachment.

## Concept Development
Bonded Steel Sandwich Panel




LOAD DEFLECTION COMPARISON




USS

**Concept Development**
Bonded Steel Sandwich Panel

**Concep...**
**Bonded Steel San...**

## TORSIONAL STRENGTH